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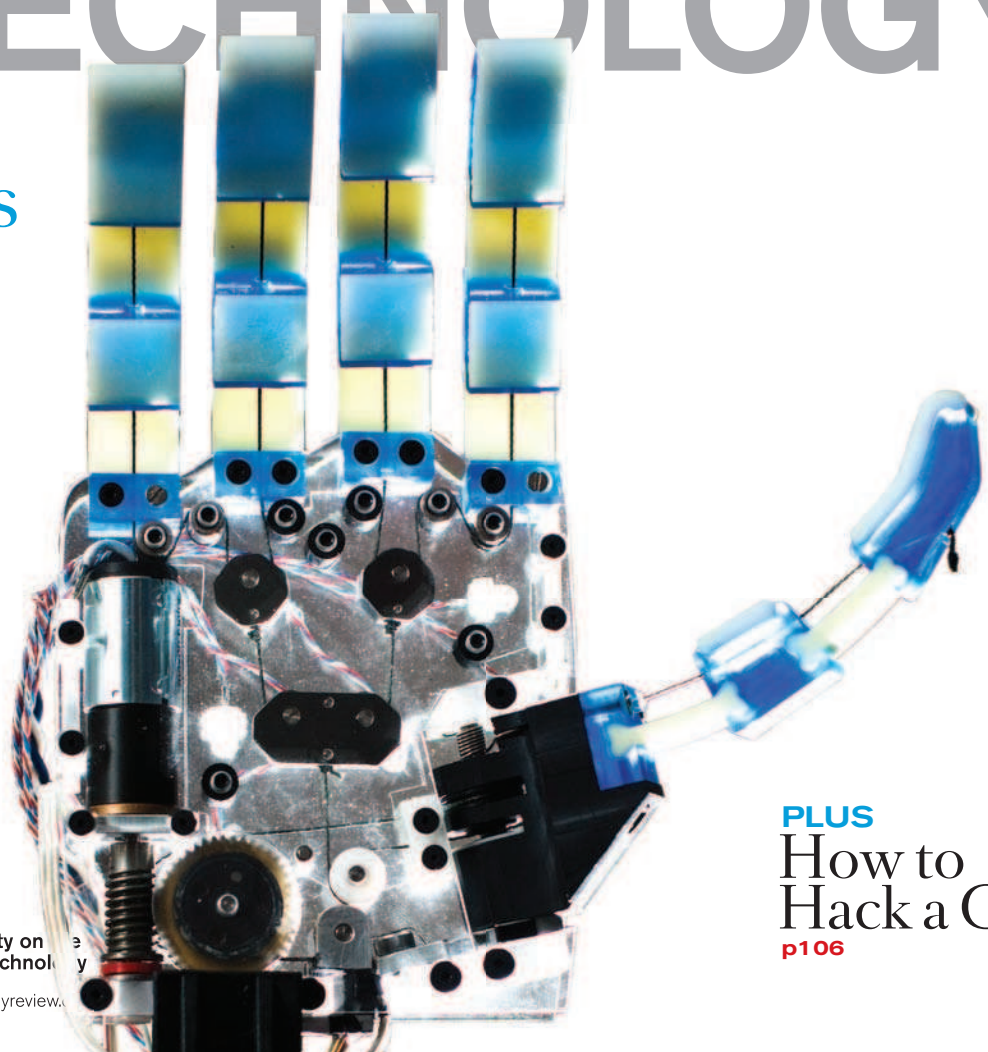

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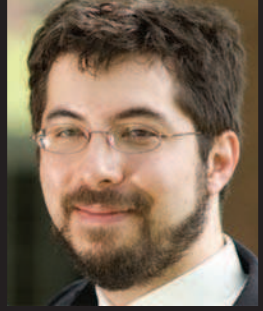

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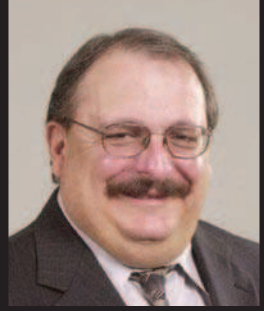
MIT Media Lab



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COVER
Robotic hand invented by Aaron Dollar, one of this year's TR35. Photo by Porter Gifford.

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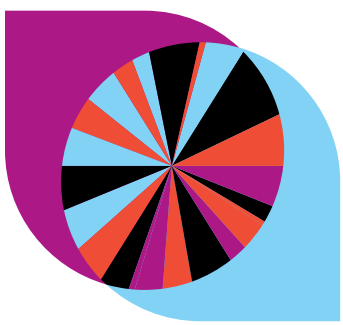

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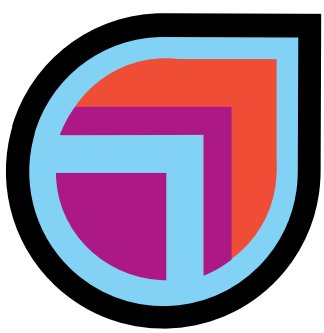

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MOVING TOWARD A CURE

Jon Cohen's article ("Can AIDS Be Cured?" July/August 2010) provided a refreshingly optimistic view regarding the potential to cure HIV infection. As vice president and director of research at amfAR, the Foundation for AIDS Research, I can say we have long shared such optimism. Just as current treatment combines several agents for suppression of the virus, it's likely that a cure will combine many approaches. This thoughtful article helps to dispel the skepticism that hinders progress in this area and highlights the need for sufficient resources and coördinated efforts that will lead to an AIDS cure.

Rowena Johnston
New York, NY

Congratulations to *Technology Review* for being the first publication to cover the renewed drive to find a cure for AIDS. As executive director of the AIDS Policy Project, I have seen this research accelerate and evolve in just the past two years. However, funding for it has not. The NIH devotes only 3 percent of its AIDS research budget to a cure; it spends nine times more on AIDS vaccines. Money is needed for short pilot studies to test therapies in humans, among other projects. Yet if we can fund the science properly, fast-track therapies ready for clinical trials, and untangle the red tape for researchers, there is a real chance to develop a workable cure in the next several years, instead of the next few decades. And wouldn't *that* be something?

Kate Krauss
Philadelphia, PA

July/August '10

SOLAR ISSUES

The fine articles on solar energy in the July/August 2010 issue ("Solar's Great Leap Forward" and "The German Experiment") highlight two renewable-energy success stories, but the use of the term "grid parity" is misleading. It implies that solar energy cannot compete with coal and petroleum. But when factors such as global warming, the Gulf oil cleanup, and the huge subsidies we give petroleum are taken into account, solar already surpasses grid parity. Defining grid parity is a good step to making better decisions for the future.

Steve Waller
Washington, DC

"Solar's Great Leap Forward," while describing the successes of China's Suntech, suggests opportunities that still are open to U.S. companies. First, although an innovative process design that takes advantage of low-cost labor has sharply reduced Suntech's cost of producing multicrystalline photovoltaic panels, U.S. companies can use other technologies that may have even lower costs. Second, only half the cost of a solar installation comes from the solar panels. U.S. companies can prosper by driving down the balance of system and installation costs. Third, the large-scale penetration of solar in the electric grid will require innovations in systems integration and management of intermittency, providing more business opportunities. Finally, innovations in business models, including clean-energy bonds, offer chances for U.S. leadership. As solar panels mature as a commodity market, we may find manufacturing predominantly outside the U.S., while most of the economic value of selling and installing solar panels is captured within the U.S.

Douglas Arent
Executive Director, Joint Institute for Strategic Energy Analysis, National Renewable Energy Laboratory, Golden, CO

James Sweeney
Director, Precourt Energy Efficiency Center, Stanford University, Stanford, CA

UNMANNED MISSIONS MORE FEASIBLE

It is understandable that Buzz Aldrin, the second man to set foot on the moon, would advocate a permanent human presence on Mars (Q&A, July/August 2010). But stating that we need a place to go "in case somebody or something blows up Earth," and that human travelers be given one-way tickets, is juvenile. As renowned space leader Si Ramo has argued, the logistics and cost of manned missions to Mars would be overwhelming, and the dangers to the astronauts would be unacceptable. Ramo also states that no scientific questions have been raised that cannot be addressed equally well by robotic spacecraft.

Michael Horstein
Los Angeles, CA

SAFETY IN THE CLOUD

"Moore's Outlaws" (July/August 2010) highlights the danger posed by attackers in cyberspace and makes the case for deploying stronger cyber security measures. As researchers at Microsoft Research, we believe machines need to be re-architected to protect against intrusion and confine the effects of an attack. This is critical on all machines but mandatory when using shared infrastructure, particularly as sensitive health and financial information moves to the cloud. Safe practices for preserving confidentiality of data through encryption should be employed. Transactions between parties on the Internet and within a machine should be routinely authenticated. Widespread use of cryptographic techniques will not protect against everything (e.g., social-engineering

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attacks aiming to steal identities), but it will help to isolate and identify vulnerabilities.

Kristin Lauter and John Manferdelli
Redmond, WA

FASTER CONNECTIONS

Your brilliant July/August 2010 Graphiti on broadband penetration created a controversial response in my Emerging Markets Business Intelligence team at Cisco. We abandoned the "cost" dimensions in our analysis of global broadband penetration because the data for emerging-market countries seem unreliable. Also, in larger countries, broadband costs and penetration vary within the country. For example, recent data for Russia show the cost of broadband varying from 1.2 percent of an average salary in Moscow and St. Petersburg to 15 to 20 percent in more remote parts of the country. The study notes that higher prices are caused by lack of competition in the regions, keeping penetration well behind what we see in the major cities.

Katya Wilkins
Feltham, United Kingdom

www Is this a fair comparison? Many of these countries have smaller areas or different population densities, which can affect the metrics. It may be easier to roll out the necessary communication equipment in a smaller area to reach a larger density of users.

ebresie
(Eric Bresie, Grapevine, TX)

Unfortunately there is no "fair" comparison in a metric like this. It will be more capital intensive to lay cables where the distances between subscribers are farther. But access should be similar assuming the same generation of equipment is serving similar numbers of subscribers. For example, Manhattan has a similar urban density to Japan, but Manhattan has slower and pricier broadband. There is no justification for it beyond regulatory and competitive differences.

colinnwn
(Joel Colin Gebhart, Dallas, TX)

NOTEBOOKS

Expert opinion

VENTURE CAPITAL

Finding People to Reinvent the World

CHOOSING STARTUPS TO INVEST IN IS A HUNT FOR PEOPLE AS MUCH AS TECHNOLOGY, SAYS WESLEY CHAN.

As an investment partner with Google Ventures, I am often asked how I decide which startups to back.

An encounter in a tiny San Diego office in mid-2004 helps illustrate my answer. There I met Paul, Brett, Jack, and Scott, the scrappiest and most creative founders I had ever seen. They constructed their own office furniture to save money. To increase awareness of their product, they would sneak into trade-show parties sponsored by well-funded competitors and bribe bartenders to distribute hip-looking decals. Without much money in the bank and under heavy competition from a dominant market leader, they proved themselves able not only to survive but to thrive. They had created a service that was well designed and had immense potential. They knew exactly how to adapt their product to handle 10 times as many users when success came, but they built it without spending on expensive equipment to serve users they had not yet acquired.

Six months later I led the acquisition of their startup, Urchin Software, which became the inspiration and foundation for one of our most successful products, Google Analytics. But for all its founders' good points, acquiring the company was not the obvious choice. Skeptics inside Google pointed out that Urchin was not the market leader or even the best-known among the 30 analytics providers we considered. I had to pound my fist on the table in many meetings, declaring that this was the right horse to back.

When people ask why I was so certain, my response harks back to that meeting in San Diego. Urchin's founders, who are all still with Google, may not have had the best-performing startup, but they were the best founding team around. Great founders need the technical aptitude, motivation, and personal skills to make a product take off. They proved they had all that when, 72 hours after it launched, Google Analytics was overwhelmed by demand. Paul and his team rapidly recruited and motivated new talent to rearchitect the service's back end. Analytics opened shortly afterward with the capacity to handle an order of magnitude more traffic. Great founders understand how to deal with unprecedented issues and come out ahead.

They also use feedback from users and the market to dramatically increase their product's growth. For example, we decided to offer Analytics free of charge when we realized that this would allow Google to engage online advertisers it hadn't been able to reach before.

So how do I invest at Google Ventures? When I fund a company, I'm looking for people with the kind of potential that Urchin's founders displayed: extraordinary entrepreneurs who can build game-changing products.

WESLEY CHAN IS A PARTNER AT GOOGLE VENTURES, THE COMPANY'S VENTURE CAPITAL INVESTMENT ARM. HE IS ONE OF THE 2010 TR35 (P. 56).

SOCIAL NETWORKING

Why Privacy Is Not Dead

THE WAY PRIVACY IS ENCODED INTO SOFTWARE DOESN'T MATCH THE WAY WE HANDLE IT IN REAL LIFE, SAYS DANAH BOYD.

Each time Facebook's privacy settings change or a technology makes personal information available to new audiences, people scream foul. Each time, their cries seem to fall on deaf ears.

The reason for this disconnect is that in a computational world, privacy is often implemented through access control. Yet privacy is not simply about controlling access. It's about understanding a social context, having a sense of how our information is passed around by others, and sharing accordingly. As social media mature, we must rethink how we encode privacy into our systems.

Privacy is not in opposition to speak-

NICK REDDYHOFF

ing in public. We speak privately in public all the time. Sitting in a restaurant, we have intimate conversations knowing that the waitress may overhear. We count on what Erving Goffman called "civil inattention": people will politely ignore us, and even if they listen they won't join in, because doing so violates social norms. Of course, if a close friend sits at the neighboring table, everything changes. Whether an environment is public or not is beside the point. It's the situation that matters.

Whenever we speak in face-to-face settings, we modify our communication on the basis of cues like who's present and how far our voices carry. We negotiate privacy explicitly—"Please don't tell anyone"—or through tacit understanding. Sometimes, this fails. A friend might gossip behind our back or fail to understand what we thought was implied. Such incidents make us question our interpretation of the situation or the trustworthiness of the friend.

All this also applies online, but with additional complications. Digital walls do almost have ears; they listen, record, and share our messages. Before we can communicate appropriately in a social environment like Facebook or Twitter, we must develop a sense for how and what people share.

When the privacy options available to us change, we are more likely to question the system than to alter our own behavior. But such changes strain our relationships and undermine our ability to navigate broad social norms. People who can be whoever they want, wherever they want, are a privileged minority.

As social media become more embedded in everyday society, the mismatch between the rule-based privacy that software offers and the subtler, intuitive ways that humans understand the concept will increasingly cause cultural collisions and social slips. But people will not abandon social media, nor will privacy disappear. They will simply work harder to carve out a space for privacy as they understand it and to maintain control, whether by using pseudonyms or speaking in code.

Instead of forcing users to do that, why not make our social software support the way we naturally handle privacy? There is much to be said for allowing the sunlight of diversity to shine. But too much sunlight scorches the earth. Let's create a forest, not a desert.

DANAH BOYD IS A SOCIAL-MEDIA RESEARCHER AT MICROSOFT RESEARCH NEW ENGLAND, A FELLOW AT HARVARD UNIVERSITY'S BERKMAN CENTER FOR INTERNET AND SOCIETY, AND A MEMBER OF THE 2010 TR35 (P. 49).

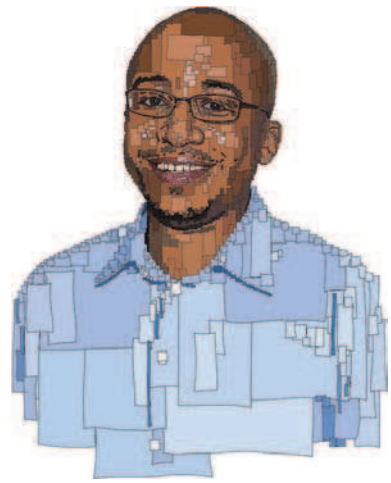
CROWDSOURCING

Communicating During a Crisis

SOCIAL SOFTWARE, SAYS DAVID KOBIA, CAN HELP DURING A CATASTROPHE—AND AFTER.

Ushahidi was created in response to the crisis after the failed elections in Kenya in 2007. In our quest to minimize the impact of riots and unrest around the country, we developed a free open-source platform that allows people to report incidents they witness. Their reports are added to an online map that rapidly becomes a source for information neglected by media and governments.

Watching Ushahidi in use after disasters like the Haitian earthquake has shown that in a crisis, the barriers of complacency and cultural indifference break down. People directly, indirectly, and even remotely involved in a situation are suddenly open to collaborating and sharing. It is at this moment that the crowd is the most powerful. Once the crisis is over, though, apathy breaks up this cohesion. With Ushahidi, in keeping with a pattern seen in other social media, a mere 1 percent of participants actively contribute new content, 9 percent interact with it,



and the other 90 percent are mere viewers. These ratios slide further toward passive viewing once an event is no longer front-page news. Finding ways to help keep the crowd engaged beyond the crisis is one of our greatest challenges.

Like anyone trying to promote user engagement, we must relentlessly remind people of our message to encourage them to use the service. We have to connect different sources of information that otherwise would never be linked. Adapting Ushahidi to incorporate social media is a big part of our strategy: it encourages user-generated content and gives everyone a front-row seat as events unfold.

After a user reports a crime or a dangerous situation, the balance between give and take is crucial. A first responder can take action if appropriate, or the person who reported the event can sign up for alerts of similar events reported by others nearby. All this is made possible by tools like text messaging and mobile-phone applications that reduce the barriers to participation.

Ushahidi has often been described as simply a map with red dots. That is not far from the truth. But people often forget that behind each of those dots is a human experience—perhaps a life or lives that have been touched by disaster. TR

DAVID KOBIA IS DIRECTOR OF TECHNOLOGY DEVELOPMENT FOR USHAHIDI AND A MEMBER OF THE 2010 TR35 (P. 44).

35 Innovators under 35

HOW AND WHY WE CHOOSE OUR YOUNG LEADERS

Every year, *Technology Review* lauds 35 innovators under the age of 35. They are chosen because they are transforming technology.

Our process for selecting the innovators is rigorous—not to mention arduous for our editors. We seek nominations more than six months before we announce the winners. Candidates, who may come from either industry or the academy, are nominated through a form, open to all, on TechnologyReview.com, or through nomination by an editor.

An important source of the latter nominations are the editors of *Technology Review*'s editions in Germany, India, China, Italy, and Spain: we want our list to be as international as possible, because technological innovation is a global enterprise, and because we are particularly interested in innovations that will solve persistent problems in the developing and poor world. The nominees are screened for appropriateness, and we collect curricula vitae, personal statements, and at least three reference letters. Simultaneously, we convene a panel of judges who are experts in different technological fields and who may be past TR35 winners themselves. We ask each judge to assess about 10 candidates. The editors consider the final list, which may include several hundred names, weighing the judges' comments and seeking a mixture that represents current trends in emerging technology and the diversity of innovation around the globe. The list is whittled down until 35 innovators remain.

The whole process, as well as the editing of the stories about the young innovators, is led by Stephen Cass, *Technology Review*'s knowledgeable, wise, and eloquent special-projects editor, who writes in the introduction to the TR35 *(p. 43)*, "We strive to identify those individuals who are tackling problems in a way that is likely to benefit society and business. ... We pay special attention to those solving some of the most intractable and critical problems in the developing world." He notes that this approach can lead to the selection of a technologist who is developing new materials for new devices—and also to rewarding an entrepreneur who is creating new business models that will move technology from the laboratory to the marketplace.

Over the last decade, many of the young innovators we've selected have gone on to be spectacularly successful. Previous winners include Larry Page and Sergey Brin, the cofounders of Google; Mark Zuckerberg, the cofounder of Facebook; Helen Greiner, the cofounder of iRobot; Jonathan Ive, the chief designer at Apple; Max Levchin, the cofounder of PayPal and founder of Slide; David Berry, who cofounded and funded (as a venture capitalist at Flagship Ventures) the biofuel companies LS9 and Joule; and MIT neuroscientist Ed Boyden, one of the inventors of the emerging field of optogenetics, which makes it possible to control neurons with light.

This year's winners have created innovations over a wide variety of fields, including biomedicine, energy, materials, communications, and transport, as well as software, hardware, social technologies, and the Web.

And as we do every year, we have selected for special attention a Humanitarian of the Year *(p. 44)*, the TR35 winner who we believe is most likely to improve the condition of humanity. This year, the winner is David Kobia, a Kenyan expatriate who designed the open-source Web service Ushahidi (the name means "witness" in Swahili). Ushahidi collects citizen reports and pinpoints them in space and time on an interactive map so that election fraud or ethnic violence can be more easily reported. It also makes it possible for first responders to disasters to react more rapidly and effectively. Since Kobia created the service as a way to document the violence following the disputed Kenyan presidential election of late 2007, Ushahidi has become central to coördinating the response to crises around the world.

Although Kobia is especially concerned with the plight of the world's dispossessed and unfortunate, he shares something with all the young innovators this year and in the past: they inspire and expand our sense of what is possible. The innovations of the TR35 allow human beings to do something difficult that they were not able to do before.

Please read this year's list, and write to me and tell me what you think at jason.pontin@technologyreview.com.

—Jason Pontin

MARK OSTOW

TWENTY-FIRST-CENTURY TRAFFIC TECH

Imagine this: you set out to drive across town to meet a friend. Before you start, you pull up a map of the route on your car's navigator. Anticipating the traffic expected during the next twenty minutes and the approximate duration of the drive, your navigator suggests a route that should be the least congested. You click to accept the route and follow it to your destination without incident.

Once you arrive, LED signs on the street point you toward blocks with available parking and alert you to the nearest recharging station. Wasting no time circling the area, you slip into a free spot, plug your car into the post, lock up, and use your phone to pay for two hours of parking and charging.

This scenario is not so far in the future. Spanish companies, which have achieved international prominence in traffic planning and modeling, tolling, lighting and signage, and guidance systems, are harnessing the latest technological advances, working to create this reality in cities around the world.

PHOTO COURTESY OF IMAGO

PHOTO COURTESY OF CYNTHIA GRABER

KEEPING IT ALL MOVING

As urban populations continue to grow, traffic pressure on existing roads and highways increases, although many cities in western countries have expanded their built environment nearly to the limits of what is possible. City and national managers are also concerned about pollution and global warming: urban traffic contributes up to 40 percent of a city's carbon dioxide emissions, and about 70 percent of other pollutants, such as nitric oxide.

In response, says Rafael Morán, Madrid's associate director of traffic and planning, "We first need to convince people to use public transportation . . . . And then we have to facilitate the movement of vehicles."

Adds Pablo Barceló, COO of Barcelona-based Bitcarrier, "The only alternative is optimization" of current roads, "to make better use . . . of the infrastructure that we already have," in order to avoid increasing traffic and to reduce emissions from idling. To accomplish this, Spain's Traffic Authority, part of the Ministry of the Interior, has invested significant funds in intelligent transportation systems (ITS) over the past twenty years.

Communications and computing power are already altering the way we drive. Cell phones and GPS navigators send out signals that allow managers to monitor the volume and speed of cars on the road. And the movements of buses, cars, and trucks are monitored in real time, with drivers alerted by their on-board navigators and by roadside signs to the best routes to take to avoid snarls. Systems like these, which employ the tools of the high-tech economy to keep traffic flowing, are some of the latest examples of ITS that are starting to enter the market.

In order to speed up city bus rides, Grupo Cegasa, headquartered between Bilbao and Pamplona (specialists in providing road signs called variable message signs and communications among those signs, vehicles, and control centers) is developing a technology to give traffic preference to buses, controlling access in special dedicated lanes. A GPS onboard a bus communicates its location to a central computer in a control center, which relays that location to traffic lights. The system monitors the occupancy of the dedicated lanes so when the bus approaches a signal, the signal remains green long enough to allow it to pass.

To manage the flow, traffic controllers, sitting by screens that show a scattering of city roads, need access to real-time information about the location and speed of vehicles all around the city. One of the most significant changes that supports this effort is the use of travelers as information producers, rather than simply information consumers. "All the systems [in use, such as mobile phones and GPS systems with Bluetooth con-

nections] are generating huge amounts of information," says Francisco Cáceres, chief technology officer at Madrid's Telvent.

And Bitcarrier is one of the first two companies in the world to commercialize a product that picks up on these signals to count vehicles on the road.

COUNTING WITH SIGNALS

Today, traffic counting is generally accomplished by using inductive loops buried under the road, which register the magnetic interference of cars passing over them; since this is expensive and time-consuming to implement, few intersections can provide this critical information. Though other technologies for continuous traffic counting have been developed, they are too expensive to be widely used.

Bitcarrier's founders believed they could devise a method to capture the public Bluetooth signals that emanate from consumer products, each with an individual signature. "The signals are public—you cannot track the person—but you can track the device," says Barceló.

To date, in most Western countries, about 30 percent of cars and trucks—or their drivers—are equipped with a smart phone or GPS system. The proprietary sensor that Bitcarrier has developed can be hung from a traffic light or lamp post and plugged into a socket with no additional infrastructure, and it can pick up the signals from equipment that passes within approximately 120 feet.

This equipment collects data about both the number of vehicles on the road and their average speed, as the sensors can monitor when specific signals pass multiple sensors. Wireless transmission directs this information to a central computer, where highway managers can use it to notify drivers about congestion and driving times ahead. The system can also alert operators immediately to traffic jams from accidents.

This idea was conceived four years ago, and for the past year and a half Bitcarrier has been creating the device and testing its accuracy. In February 2010, after an eight-month trial period, the transportation concession Abertis Infraestructuras—which operates toll roads in Spain and other countries—bought 150 units to monitor traffic on a major Spanish highway. Abertis has already announced that it will purchase additional units for other roads. The city of Zaragoza, in northern Spain, has decided to blanket the city with these sensors to capture nearly 100 percent of city traffic flow information, and inquiries are coming in from around the world.

PHANTOM TOLLBOOTH SYSTEMS

Traffic traditionally slows to a crawl at tollbooths. To counter this, companies and cities have been using onboard tags that allow vehicles to drive through without stopping. The advanced information systems and systems integration company Tecsidel, which designs and supplies tolling systems around the world, is one of the few international companies that has moved beyond barrier-free tolls to create an open tolling system. In this system, implemented by Tecsidel in Oslo and elsewhere in Norway, cars continue moving at normal speed when approaching a toll; the toll scanner stretches over the highway like a traffic signal. This can save fuel by preventing traffic jams, and the scanner can be installed rapidly without major remodeling of the road.

As vehicles zoom underneath the apparatus, overhead cameras pick up a vehicle's image at speeds up to 120 mph (200 km/h). If the vehicle has a tag, like an EasyPass in the U.S., the user is charged automatically. Otherwise, the license plate's image is captured and deciphered by a software program that then sends a charge to the driver.

"Everything is based on the quality of the pictures," says Gerald Pelle, Tecsidel's marketing director. "It's a mature technology, but there are still limitations: if there's a lot of snow or dirt, the license plate is not even readable by human eyes." The Tecsidel apparatus captures both front and rear plate images to minimize such challenges.

Today there's a trend in some places—Portugal, for one—to equip cars at purchase with ID tags, similar to license plates, that can facilitate country-wide free-flow toll systems. Madrid-based Indra Sistemas, a world leader in information and communication technologies, with projects in more than 100 countries, will introduce the first such automated toll system in Portugal, on a stretch of highway that runs north to the Spanish border. Indra's payment platform can handle up to 1.5 million transactions a day.

Indra integrates technologies that are available on the market into complete systems, marketing them throughout Spain and in Europe, Asia, and the Americas. Indra manages ITS for nearly 2,500 miles of Spanish highways and controls toll lanes and plazas in 15 countries. Leveraging their defense experience, Indra engineers have developed a product that capitalizes on radar technology from Spain's Department of Defense to provide a more advanced radar system for civilian roads.

Indra is one of a number of systems integrators (which include major international companies such as Telvent and Sice) which develop their own products in house while also integrating available technology to present a cities or regions with complete traffic management. Telvent supplies intelligent systems that control traffic at more than 9,000 intersections a day, and toll networks that handle 1.5 million vehicles annually; its clients include the New York State Department of Transportation and the Municipal Corporation of Greater Mumbai.

Sice integrates complete highway solutions in Europe, Latin America, and North America, and at times operates highway road tolls as a concessionaire standing in for a public authority. In Melbourne, Australia, "we're capable of managing 8 million transactions a day [in tolls]," says Angel Aguilar, Sice's international director.

According to infrastructure director Vicente Sebastián of Grupo Etra, which provides integration service to cities such as Madrid, his company's goal is "to optimize the hardware with the

VIRTUAL VALET PERFECTS PARKING

Cities often frustrate drivers in search of parking; cars weave through city blocks, wasting time and burning gasoline. Parking cars quickly could improve mobility and help cities meet environmental goals of reducing carbon dioxide and pollution.

What if drivers could be directed to available spots immediately upon arrival at their destinations? Parking efficiency possibilities have inspired Barcelona-based ParkHelp's directors, who originally founded their company to focus on embedded electronics connected to the Internet. That work morphed into a successful project creating the parking guidance system for Madrid's new ten-thousand-space airport parking garage, one of the largest such systems in europe.

ParkHelp engineers designed proprietary sensor holders, which use no screws, and built their own cables, eliminating most connections, creating a system that can be easily and quickly snapped into place.

Sensors communicate the occupancy status of each space on a given floor to an independent processor on that floor. The floor processors communicate with each other and with a central computer. "When we finished, the result was the most complete project available on the markets for airports and projects of this size," says company cofounder Alexis Puig: the company has since won contracts for similar projects in 22 countries.

In 2007, ParkHelp decided to try to create something that did not yet exist. "We said, let's see how our successful experience in parking [garages] can translate into parking in the city," said Puig.

First, company engineers needed to identify the best sensor available, one that uses little battery power. They decided on a new technology that operates by registering the earth's natural magnetic field, then sensing when it's disturbed by a huge amount of iron—a vehicle—in that field.

Once alerted to the presence of a vehicle, the sensor sends the information to a control center. That computer aggregates the vehicle information and automatically updates LED signs to alert drivers to available spaces.

In the future, this information will also be uploaded to a website, even directly to a car's GPS. "You'll be able to program in to your GPS, 'I want to go to this area of the city,' and when you get there, it'll direct you to a parking spot," predicts ParkHelp cofounder ignacio Maluquer.

A prototype system very like that has already been set up in lleida, a city of almost 40,000 just north of Barcelona, and will soon be available in other Spanish cities, including Malaga and Madrid. Cities around the world have expressed interest, in part due to the clear environmental benefits. But beyond that, the return on investment for cities or companies that manage city parking happens quickly, say company directors, because drivers pay for the parking time they occupy, the turnover is rapid, and infractions are easy to enforce.

PHOTO COURTESY OF PARKHELP

most efficient use of energy, at the least cost, and integrate" all the elements of a complete system from different manufacturers. In addition to integrating services, the company develops and manufactures the core computer systems they deploy. They're working on a novel means of communicating with the public: in Madrid, they've designed a system whereby riders can send a text message with the bus number and stop identifier, and immediately receive back a text with the arrival time of the approaching bus.

PREDICTING TRAFFIC

In an ideal world, traffic managers need to peer into the near and distant future to evaluate traffic control options. How will a road closing affect vehicle flow, and what are the best routes for redirecting cars and buses? When an event such as an accident occurs, what are the best diversion plans to facilitate movement?

Tekia Ingenieros (Tekia), based in Madrid, has been tackling the planning for traffic control in tunnels. The company's most ambitious project to date involved analyzing the safety needs of the newly built tunnel section of one of Madrid's ring roads; it is buried under a river, and the tunnels stretch out for more than 30 miles (50 km), making it the world's longest underground automobile traffic structure.

Tekia engineers looked hard at potential safety threats to the tunnel, such as heavy traffic, or accidents, fires, or explosions. They brought together a roundtable of security experts for a year. Using all the expert information and possible scenarios gleaned as part of their program, and aiming for the best outcomes for each scenario, Tekia then built an expert operating system to help a city planner decide in real time which solutions would best solve problems that arise.

Such traffic modeling software is the specialty of Transportation Simulations Systems (TSS), a Barcelona-based traffic modeling company offering more than 25 years of experience helping cities plan for traffic flow.

TSS developed its modeling program, Aimsun, using research performed at a Barcelona university. At the time, in the 1980s, company founders realized that the big-picture regional models that were being used for strategic planning might be able to predict population and traffic growth on a large scale, but were not much help in determining the best solutions for small-scale changes in traffic.

Company engineers wanted to create a model that could examine behavior on the micro level. "What will happen if there's road work on a major arterial that also has a tramway and lots of traffic? You can experiment with adjustments to make the situation more tolerable—maybe change the light settings, restrict access to some roads, or send the police out to direct traffic," says Alex Gerodimos, TSS commercial director. Despite the much lower computing power available at the time, TSS's new models were able to accurately predict the results of interventions on this more modest scale.

But while this was helpful for planning, these models could not yet assist real-time traffic management. Since then, leaps in computer processing speeds, coupled with the greater quantity of real-time information now available on the details of traffic flow, have allowed a revolution in modeling: TSS and its partners have developed both small- and larger-scale Aimsun models that can be used by city traffic managers to determine the consequences of changes to traffic in real time, allowing them to make rapid decisions based on predictions from the models.

For instance, an ambulance might need to reach the scene of an accident, but that accident has already caused changes in traffic that are rippling outward. The models can provide images of the possible ambulance routes and suggest which will be the fastest.

In Madrid's municipal traffic control center, the graphic simulations hover on a screen, allowing the controller to visualize the consequences of particular choices 10 to 20 times faster than they would occur in the real world. The Aimsun software used here is used to model traffic for other cities in 60 countries, including the entire nation of Singapore.

Telvent uses a modeling program for its control systems, and has been able to incorporate weather and pavement conditions into the traffic management systems for cities such as Alberta, Canada. "We can use weather information for precise support. For instance, we can predict what the pavement conditions will be over the coming hours," says Cáceres.

SMART INFORMATION FOR SMARTER TRAVELERS

Drivers today can take a quick glance at a number of web pages that claim to show current traffic conditions. "We believe this information is inferior—or in some cases useless," points out Gerodimos. "It's often based on what we know now." But if the information is not available, because a particular road isn't monitored for traffic, it appears traffic-free, no matter what the actual conditions. A model can solve that issue, he explains, by extrapolating for the entire city.

And the second problem, he says, is that the driver hasn't left the house yet, and traffic may change rapidly. Gerodimos envisions a future in which predictive models will be available not just to traffic control managers, but to consumers as well. With software such as Aimsun running, the car's GPS system could not only offer current traffic conditions, but recommend the best course for a 30-minute drive based on future traffic patterns.

"If we provide consumers with smart information about options for mobility, we'll improve both mobility and the efficiency of the infrastructure," explains Telvent's Cáceres.

Supplying easily accessed information is the goal of the system designed by Telvent for New York City, San Diego, and Tennessee. It relays real-time information on traffic and public transportation via the Internet. Citizens can also dial 511 to listen to up-to-the-minute responses provided by a computer-generated interactive voice response system.

Today, many consumers receive information about traffic

when they're in the midst of it, on the road, through brightly lit displays called variable message signs. These signs—typically LEDs —look simple, says CEO Tony Batlló at Imago Screens, one of the top LED sign manufacturers in the world for traffic and for events such as sports. "In reality, the needs for traffic [as opposed to sporting event screens] are much higher," he continues. "They need 100 percent security, functionality, and performance, 24 hours a day. The reliability is crucial."

The LEDs themselves form the base of the signs, and company engineers then carefully design the optics and the control systems to specific brightness, contrast, and luminosity, depending on the sun conditions in a given country, and even on a given day. "It's important to be able to see the sign clearly," says Batlló. "But if it's too bright, then it hurts your eyes and you can't read it." Sensors built into the screens detect the light conditions and modify their brightness automatically.

The sensors on the LED panels can offer additional information to road managers. "The panel can be programmed to tell the controller, 'It's raining; do you want to display a message about rain?' The operator can say yes or no," explains Batlló. "In the future, roads will have devices that can communicate with each other in a kind of network, with cameras, sensors, weather stations, and a network of information that will include even the user's vehicle on the road."

NEW WAYS TO NAB BAD DRIVERS

As recently as 2005, Spain had one of the highest numbers of accidents per person in western Europe. Through the use of new technologies, the country managed to reduce deaths dramatically: "We've gone down by more than half in less than five years," says Alberto Arbaiza, in charge of ITS projects at the Ministry of Interior's Traffic Authority.

In speed management, standard techniques until now have relied on fixed locations, either a cop with speed-catching radar or a signpost that flashes a driver's speed as he drives by. The challenges presented by these fixed positions is that it's relatively easy for a passerby to slam on the brakes and then immediately hit the accelerator.

To replace them, Grupo Cegasa has developed a system of what's known as *section speed*. This technique works by capturing a car's position first at one location, then at a second one down the road, then calculating the speed that it took to traverse that segment. The license plate numbers of speeders are captured and sent to the authorities. "This is not only an alternative way to measure speed, but it's also safer, and more fair," says Alfonso Vazquez, international sales director, and it slows the overall speed of the traffic.

Traffic accidents are also caused by drivers hurtling through red lights. Today, the latest technology at intersections involves an inductive loop under the street; as the light turns red, a car passing over the loop triggers cameras that capture the car's image. Barcelona-based Quercus Technologies recently unveiled the first system in the world that operates on a small moveable system of cameras, which works independently from traffic lights or traffic controllers.

Quercus has built on its experience in artificial vision—they're one of the top producers in the world of license-plate recognition systems—to create a noninvasive technology. "It's what we call virtual loop technology," says Silvia Vilanova, Quercus marketing director. "All the recognition you need is in the camera and you don't need any sensors in the road."

The camera faces the light and picks up on the location of light emanating from the signal. When the light changes from green to red, the position of that light changes, and it triggers the camera, which snaps a series of shots as the car traverses the intersection. This product, launched in March 2010, has a number of added advantages: it is significantly cheaper than the alternative, and it demands no additional street work. In addition, research has shown that after the implementation of a system to capture transgressors at a light, that particular intersection becomes safer within a year or two. But the traditional loop-based infrastructure is prohibitively expensive to move. Quercus's camera, however, can be readily lifted and recalibrated to the specifications of a new intersection.

HELPING TRANSIT SEE GREEN

To help transit systems communicate with public transportation users, Tekia engineers developed a system of predicting bus arrival times based on on-board GPS systems. They soon realized that the equipment could be enhanced to contain more than just a GPS unit, and could provide information beyond location. This information could reduce a driver's fuel consumption and thus her emissions.

The Tekia system contains a small computer that monitors the driver's speed and acceleration, immediately comparing these against an optimal model to encourage the driver to use the smallest possible amount of fuel, such as slower acceleration. The system is now being tested in Madrid.

"When we present this to bus operators, they're very interested; they see that it can be translated directly into cost savings," says Alejandro Sanchez, business development manager. The company estimates that the systems can pay for themselves in fuel savings in about three to four years.

Indra offers a system for making environmental measurements—of carbon dioxide and other city pollutants such as nitric oxide— in real time and sending that information to traffic managers "so that they can see if, for instance, the center of Madrid is overwhelmed with pollution, and they can make the decision to reroute traffic," says Mario Hornero, manager of Indra traffic projects in Latin America.

These environmental advances, however, are incremental steps designed to fine-tune the current transportation system. Many companies are designing complete transformations of the way we move and power our vehicles.

Grupo Cegasa, in a partnership led by MIT, is taking part in

PHOTO COURTESY OF

rethinking urban transportation. That MIT team has designed a two-person stackable electric city car, designed to be picked up and dropped off at locations around a city. Cegasa has more than 25 years experience in developing batteries—it's one of the top battery manufacturers in Spain—and it is researching the battery and storage systems for these new vehicles. Cegasa is also partnering with a Spanish team, which includes the automobile manufacturer SEAT, to develop the next generation of lithium batteries for SEAT's coming electric car.

All major car manufacturers are now unrolling electric vehicle models, but the infrastructure does not yet exist to support those cars. Where will owners charge their cars? How will the charging stations operate?

Circontrol, located outside Barcelona, began designing charging-station solutions more than three years ago, when electric vehicles were still considered cars of the future. Company president Ramon Cornellas decided to invest research funds in developing charging stations. Admits Moisés Barea, Circontrol's export manager, "The first time I heard this, I thought it was a little crazy, because there were no electric vehicles yet." Because of Cornellas's foresight, however, Circontrol is now one of only three companies that is actually shipping charging stations to around the world to cities that are piloting electric vehicle programs.

Circontrol is part of the Circutor group, which works in the field of energy efficiency. In 2002, Circontrol designed its first parking-guidance system, a combination of ultrasound sensors in each garage space, signal lights to alert drivers to the availability of a given parking spot, and LED signs to direct drivers through the garage. From the beginning, Circontrol's focus, leveraging its parent company's experience, was directed towards energy efficiency and savings. Circontrol quickly began to supply parking guidance to locations that include Turkey, Chile, and the Philadelphia airport.

As engineers focused on whole-garage energy systems, they realized that these locations will be prime spots for recharging electric vehicles, and began to turn research in that direction.

There are, however, a number of issues. First, there's as yet no standard for how cars will be charged, and whether they should operate off conventional plugs or use a larger charge, which would operate more quickly but demand different engineering. Engineers also found that if too many cars plug into the same source, they cause interference in the grid. They were able to solve these problems by creating a base model that can be modified depending on the types of car and plugs a manufacturer chooses.

But there are additional challenges that result from an entirely new mode of driving. How do you charge customers? "This is not just a socket—it's not something on the street where everyone can go and charge fuel for free," says Barea. So Circontrol created stations that must be activated, with either a credit card or a radio frequency identity tag that identifies the customer and can be charged to a linked account.

Security is also an issue. How do you prevent someone from unplugging a car, and then plugging in his own car on someone else's account? Circontrol built in a number of safeguards: in

PHOTO COURTESY OF CIRCONTROL

one, the charging station sends a small electrical charge out, which the car returns in a closed loop. If someone unplugs a car, that small charge drops, and so the larger charge turns off as well. They've also designed a metal "hat" that locks down over the plug after payment.

The company has already shipped more than 300 units to pilot programs across Europe. Electric cars, or plug-in hybrid electric vehicles, are now coming on line so quickly, says Barea, that "the challenge is to be ready with all our operations and logistics, with the stock ready to manufacture."

IN SEARCH OF PARKING

Parking guidance systems have been gaining ground in parking garages around the world. The Parkare group provides guidance systems for more than fifty thousand parking spaces, along with license plate recognition hardware and software, and has sold more than twenty thousand of the on-street parking meters known as pay-and-display, which replace traditional meters with a fee boxes that sell tickets to be displayed in car windows.

Parkare is investigating the best ways to use the latest technologies to facilitate parking. "If you're booking a ticket on line for a movie, we can add another button to book your car space. So you can go to the movie and know that you have a spot reserved in the garage," says Francisco Martin, international division director of Parkare.

The most efficient system to charge drivers and manage traffic in a city challenged the owners of Barcelona-based Open Traffic Systems to develop an entirely new on-street parking method, which they refer to as a "complete parking solution."

The centerpiece of the design is a payment kiosk, which not only accepts payment for the parking space, but displays an entire computer screen to manage the interaction. The user types in her license plate number, pays for parking time, and gains access to information on bus routes and local businesses.

The license plate information is then sent to a central server, which broadcasts the data to the ticketing authorities monitoring the streets with handheld PDAs. Open Traffic Systems also provides a system for the authorities to use while driving around and checking the license plates: two cameras mounted on a car scan the streets and can read the plates, matching plate numbers against ones in the system. This technology was unveiled in a 500-unit system around the northern city of Bilbao, and is now being sold elsewhere in Europe and North America.

The technology demands a greater upfront investment than traditional parking meters, according to Clint Burnette, Open Traffic Systems project manager, "but you need fewer enforcement agents, and they take less time [to figure out who deserves a fine]."

In the latest upgrade, geared towards environmental sustainability, the system can run off solar power. It also includes Circontrol's electric car charging stations as a payment option, and offers rugged, gear-free bikes (to avoid damage common to city rental bicycles) that can be paid for at the kiosk and deposited at other sites around a given city. One such pilot system has been installed in the north of Barcelona.

Even at a time of economic challenges, cities envision these systems as potential revenue sources that will yield a good return on investment, adds Burnette: "We've hired new people for the last six months, and we have so much work we'll have to hire more."

PHOTO COURTESY OF

Resources

ICEX (Spanish Institute for Foreign Trade)
www.spainbusiness.com
www.spaintechnology.com

AMEC URBIS
www.amec.es

AYUNTAMIENTO DE MADRID
www.munimadrid.es

BIT CARRIER
www.bitcarrier.com

CEGASA
www.cegasa.com

CIRCONTROL
www.circontrol.com

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TRANSPORTATION

A CHARGER FOR THE SMART GRID

THE NEW GE charging station for electric cars will fully charge a battery in four to eight hours—much faster than standard plug-in charging, which can take 18 hours. It allows two-way communication between stations and power companies, so that the utilities can minimize the vehicles' demand on the grid. GE hopes that municipalities and green-building owners will install the chargers in parking areas and that electric-car owners will buy home versions for their garages.

Product: WattStation **Cost:** $3,000 to $7,000 **Availability:** Now for commercial version; a residential version costing $1,000 to $1,500 will be announced later in 2010 **Source:** www.ecomagination.com/wattstation **Company:** GE

ERIK PAWASSAR

RENEWABLE POWER

LOW-COST SOLAR

SOLAR CELLS can produce 10 times more electricity per gram of silicon thanks to this system, which concentrates sunlight on the cells with the help of parabolic troughs and a tracking system that keeps them pointed at the sun. Concentrated sunlight ordinarily causes solar cells to overheat, impairing their performance, but this system uses heat sinks and convection to prevent that problem. The reflective troughs, a type already used in solar thermal plants that concentrate sunlight to make steam and drive turbines, can be made in high volume at low prices.

Product: High Gain Solar 1000 **Cost:** Depends on installation **Availability:** Now **Source:** www.skyline-solar.com **Company:** Skyline Solar

MATERIALS

TOUCH SCREEN TOUCH-UP

WHEN APPLIED over glass displays, these transparent conducting films make better touch screens for smart phones and tablet computers. They're more electrically conductive than the films used now, which means better touch response; they prevent electromagnetic interference from other parts of the device, so you can run more applications at the same time; and they let more light through, which means a brighter display.

Product: 3M Transparent Conductors **Cost:** Not available **Availability:** Now **Source:** www..3M.com **Company:** 3M

COURTESY OF SKYLINE SOLAR (SOLAR); CHRISTOPHER HARTING (FILM); COURTESY OF DNA2.0 (GENE)

BIOENGINEERING

Designing Genes

WANT A gene that can produce enzymes that efficiently turn organic materials into biofuels? New software makes it easy to design genes from scratch, and displays schematics (right). The company offering the software can produce the sequence, or you can hand the task to another DNA synthesis firm.

Product: Gene Designer 2.0 **Cost:** Free **Availability:** Now **Source:** www.dna20.com/genedesigner2 **Company:** DNA2.0

MEDICAL DEVICES

DISPOSABLE EEG

DETERMINING whether a convulsive emergency-room patient is having continuous epileptic seizures, not suffering from a different affliction, requires an EEG. The test normally requires trained technicians to affix a special cap and is not always performed. This disposable EEG array is so easy to use that medical staff with no extra training can fit it to the scalp in about five minutes. The device received U.S. Food and Drug Administration clearance this year; European approval is expected later in 2010.

Product: StatNet **Cost:** $595 for a box of five **Availability:** Now **Source:** www.hydrodot.net/products/statnet.html **Company:** Hydrodot

ROBOTS

BOSS ON WHEELS

REMEMBER the Segway? It never quite revolutionized transportation, but a similar mobility technology now underpins this telepresence robot, called Anybot. It glides on two wheels around an office or factory to let workers videoconference with the boss, who can control the contraption from a remote keyboard. The Anybot is equipped with an obstacle-sensing and guidance system to avoid crashing into things.

Product: Anybot
Cost: $15,000
Availability: November
Source: www.anybots.com
Company: Anybots

CHRISTOPHER HARTING (EEG); COURTESY OF ANYBOTS (BOSS)

NEXT-GEN GAMES

PLAYTIME, REINVENTED

The latest games exploit 3-D detectors, motion-capture technologies, and cloud services.

Into the Clouds

A SUBSCRIPTION service makes it possible to play graphics-intensive games without bulky consoles or high-powered computers. Games are streamed over the Internet to a PC, Mac, or television through a microconsole (above left). Processing takes place on remote servers, where the games are stored.

Product: OnLive **Cost:** First year of membership is available free through Labor Day, $4.95 per month for second year **Availability:** Now **Source:** www.onlive.com **Company:** OnLive

Watch the Hand

THE PlayStation controller uses a lighted globe at the end of a wand (two are shown above) to precisely place a character in three-dimensional space. A camera tracks the ball to determine the position of the player's hand; crucially, it uses the apparent size of the ball to gauge depth. This allows precise placement of a character's hand, which is helpful when shooting things.

Product: PlayStation Move motion controller **Cost:** $50 ($100 bundled with required PlayStation Eye camera; console sold separately) **Availability:** September 2010 **Source:** us.playstation.com/ps3/playstation-move **Company:** Sony

Body Tracker

USING a video camera and a depth sensor to follow 48 points on your head, torso, arms, hands, and legs, this device makes it possible to control game elements entirely through body movements.

Product: Kinect for XBox 360 **Cost:** $150 (console sold separately) **Availability:** November 2010 **Source:** www.xbox.com/en-US/kinect **Company:** Microsoft

COURTESY OF ONLIVE (CLOUD); SONY (HAND); AND MICROSOFT (TRACKER)


RULE THE AIR
I CAN'T CONTROL EVERYTHING,
BUT I'M GETTING
DANGEROUSLY CLOSE.
You have teams spread all over the world. Keeping them all on the same page takes a lot of coordination. With a unified communication solution from Verizon, you can stay connected to your teams regardless of their location. So while your projects may be complex, your collaboration is anything but.
VERIZONWIRELESS.COM/TECHNOLOGY
verizon
Network details & coverage maps at vzw.com. © 2010 Verizon Wireless.

DIAGNOSTICS

DESKTOP CANCER CHECK

A DEVICE that analyzes blood levels of prostate-specific antigen (PSA) is one of the first doctor's-office uses of microfluidics—technology that can manipulate fluids on a chip at microscopic scales. When a cartridge bearing a blood sample is inserted into the tabletop device, an accurate reading can be completed in 15 minutes, helping monitor the health of patients with prostate cancer. The procedure used now involves sending a sample to a lab for analysis, which often takes a day or two. The device received European approval in June.

Product: Claros DX 1 **Cost:** To be announced in late 2010 **Availability:** Late 2010 in selected European markets **Source:** www.clarosdx.com **Company:** Claros

ENERGY

CO_2 Emissions Monitor

STICK THIS device between a wall socket and any electronic equipment and it will tell you how much electricity the gadget uses, how much that electricity cost, and how much carbon dioxide was emitted to produce it. The monitor comes preloaded with costs and emission levels that reflect U.S. averages; users can also program it with local rates.

Product: Conserve Insight Energy Use Monitor **Cost:** $29.99 **Availability:** Now **Source:** www.belkin.com/conserve/insight **Company:** Belkin

CHRISTOPHER HARTING

336 Volts of Green Engineering

MEASURE IT – FIX IT

Developing a commercially viable fuel cell vehicle has been a significant challenge because of the considerable expense of designing and testing each new concept. With NI LabVIEW graphical programming and NI CompactRIO hardware, Ford quickly prototyped fuel cell control unit iterations, resulting in the world's first fuel cell plug-in hybrid.

MEASURE IT

Acquire
Acquire and measure data from any sensor or signal

Analyze
Analyze and extract information with signal processing

Present
Present data with HMIs, Web interfaces, and reports

FIX IT

Design
Design optimized control algorithms and systems

Prototype
Prototype designs on ready-to-run hardware

Deploy
Deploy to the hardware platform you choose

Ford is just one of many customers using the NI graphical system design platform to improve the world around them. Engineers and scientists in virtually every industry are creating new ways to measure and fix industrial machines and processes so they can do their jobs better and more efficiently. And, along the way, they are creating innovative solutions to address some of today's most pressing environmental issues.

>> Download the Ford technical case study at **ni.com/336** **800 258 7018**

NATIONAL INSTRUMENTS™

Taking Stock of the Stimulus

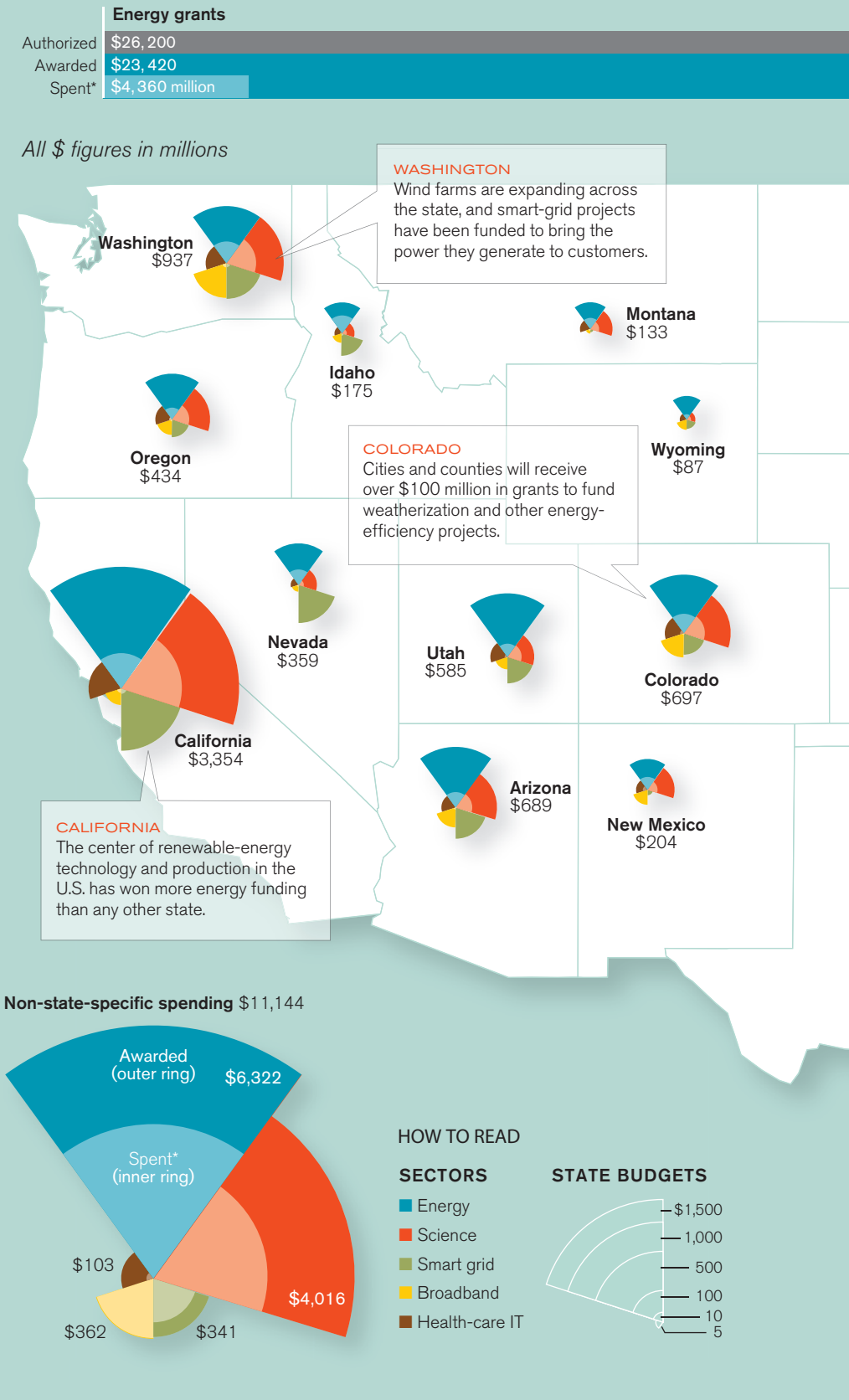
THE TECHNOLOGY FUNDING IN LAST YEAR'S RECOVERY ACT IS JUST BEGINNING TO REACH ITS TARGETS.

Most of the direct spending in the $787 billion stimulus bill passed in February 2009 was targeted at infrastructure projects that could begin immediately and provide a quick injection of jobs into a reeling economy. But the legislation also provided more than $50 billion in grants to deploy energy and information technologies, and that money will take longer to spend. While the ultimate economic value of the investment is yet to be determined *(see "Cash for Infrastructure," p. 100)*, the map at right shows that the money is at last beginning to flow. The bar shows how much money was authorized, how much of it has been awarded to specific projects, and how much has been paid out. While just $381 million of the $7.2 billion authorized to bring broadband to rural areas had been spent as of June 30, for example, nearly $2.5 billion has been awarded, and the rest should be spoken for by September. The Department of Energy, which controls $32.7 billion for clean energy, has also picked up the pace, awarding hundreds of grants to projects around the country. *—Matt Mahoney*

Information graphic by
TOMMY MCCALL

Sources: Funding reported by government agencies as of June 30, 2010, at www.recovery.gov. Individual state totals do not include funds secured through loan guarantees.

**Does not include $17.6 billion in Medicare incentive payments to health-care providers.*



TOTAL SCIENCE AND TECHNOLOGY GRANT AUTHORIZATIONS

$57,900 million

MICHIGAN
Roughly half of the $2.4 billion in grants for advanced battery manufacturing will be spent here.

PENNSYLVANIA
Received the highest share of broadband funds for bringing high-speed Internet access to underserved areas.

MASSACHUSETTS
Has grabbed an outsize share of the billions in new science funding from federal agencies.

North Dakota $102
Minnesota $537
South Dakota $122
Wisconsin $855
Michigan $1,783
Pennsylvania $1,839
New York $2,177
Vermont $225
NH $215
Maine $338
Nebraska $190
Iowa $175
Ohio $1,091
Conn. $337
RI $157
Massachusetts $1,644
NJ $552
Delaware $190
Maryland $797
Kansas $300
Illinois $1,219
Indiana $912
W.Va. $639
Missouri $609
Kentucky $361
Virginia $634
Washington, DC $706
Oklahoma $427
Tennessee $604
North Carolina $1,276
Arkansas $189
Alabama $526
Georgia $672
South Carolina $309
Texas $2,089
Louisiana $431
Mississippi $286
Florida $1,335
Alaska $365
Puerto Rico $214
Hawaii $164

NORTH CAROLINA
Will receive nearly half a billion dollars in grants to fund storage technology for wind power and a smart-grid demonstration project.

FLORIDA
Utility FPL was awarded $200 million for a smart-grid project in Miami last fall, but its CEO recently complained that he had yet to see any money.

TEXAS
A project on the Gulf of Mexico has been awarded over $250 million to capture and sequester a million tons of industrial carbon dioxide per year.

Q&A

BILL GATES

"Is that what we have in mind: to delay Armageddon for three years?"

When Bill Gates is interested in something new, his organizing, capacious intelligence learns everything about it, and he imagines ways it could be better. Now the cofounder of Microsoft and the Bill and Melinda Gates Foundation is interested in energy. At his offices in Kirkland, WA, he spoke to Jason Pontin, *Technology Review*'s editor in chief. Gates called for energy "miracles" and a more rational energy policy, and he explained how being a software "fanatic" prepared him to invest in new ideas.

_TR_: The Gates Foundation has invested in solutions to big problems like infectious diseases in poor countries. Providing clean energy for the nine billion people the planet will hold in 2050 is a problem that's civilizational in scale. What can philanthropy contribute to energy research?

Gates: Well, basically not much. The energy market is an absolutely gigantic market, big enough that if you can come up with cheap ways of making electricity, then that should be done with typical big-firm risk taking, small-firm risk taking. On the other hand, the way capitalism works is that it systemically underfunds innovation, because the innovators can't capture the full benefits [of their innovations]. But there's a net benefit to society being more R&D-oriented. And that's why in health research, governments *do* fund R&D.

You are a member of the American Energy Innovation Council, which calls for a national energy policy that would increase U.S. investment in energy research every year from $5 billion to $16 billion. I was stunned that the U.S. government invests so little.

I was stunned myself. The National Institutes of Health invest a bit more than $30 billion.

So why couldn't huge, regular, dependable investments from your foundation make a difference?

We might have some involvement where it's connected to things that wouldn't happen for poor people otherwise. So there may be some particular biomass approaches for getting local energy out where there's no roads and infrastructure, where there wouldn't be a market signal for that type of innovation.

But [as an investor] I've put my money into Vinod Khosla's venture fund. I've put money into Nathan Myhrvold [and his Intellectual Ventures fund]. Nathan has this thing that invents ideas broadly, many of which are energy-related. Some of those energy-related things will result in startups. One has so far: this amazing, wild nuclear [reactor design], TerraPower.

If energy research is underfunded by $11 billion, what is a better approach to funding new energy technologies?

It's not a problem that lends itself to a Manhattan Project–type approach. It has to be low cost and usable in different circumstances. You can't just get a bunch of smart people together and know which path they should go off and pursue. Actually, it's amazing that that worked for the Manhattan Project.

It worked because it had a very specific end: they wanted to build the biggest bomb in the world and end the war.

They knew what they wanted to do. I guess in a vague sense we can say that we want energy that costs, say, a quarter of what coal electricity does and emits zero CO_2. We can write that down. But there are many paths to get there, each of which a realist would look at and say, "Wow, there's a lot of difficult things along *that* path." So I think it's very important, both to give poor people cheap energy and to avoid hugely negative climate change, that the U.S. and other governments fund basic research. The irony is that if you actually look at the amount of money that's been spent on feed-in tariffs and you properly account for it—tax credits, feed-in credits in Spain, solar photovoltaic stuff in Germany—the world has spent a massive amount of money which would have been far better spent on energy research.

Let's talk about policy, then. The prospects for a strong climate bill in the U.S. Congress now look dim. So do the chances for any binding international treaty. But almost everyone agrees that there needs to be a price on carbon or a tax.

No, that's not right. It's ideal to have a carbon tax, not just a price on carbon, which is this fuzzy word that includes cap-and-trade. You're using the tax to create a mode shift to a different form of energy generation. And then you just take all the carbon-emitting plants, you look at their lifetime, and you say on a certain date this one has to be shut down and when a new one is put in place, it has to be low-CO_2-emitting.

That's a regulatory approach, and it's very clear. Innovators are designing things for the power-plant buyers 10 years from now, who are looking at the regulatory and tax environment for the next 40 years. If you said to a utility company executive, which is more likely to stay in place: a cap-and-trade thing, whose price will vary all over the map, that will have some international things that will be shown to be a waste of money? Or a tax and a regulatory framework for plant replacement over the next 50 years? We should have a carbon tax. What we owe the developing world is this: we're willing to pay high prices for energy plants above coal and drive prices down the curve so by the time they need to buy them, they don't have to pay the high price.

Photograph by BRAD SWONETZ/REDUX

That sounds politically unlikely.

Which is more likely: a carbon tax with all sorts of markets and options and uncertainties about prices, and traders in the middle, and confusion about who initially gets the most advantage? Or a regulatory thing and a 2 percent tax to fund the R&D so that utilities know they can buy a plant that's emitting hardly any CO_2? Raising energy prices by 2 percent and sending it to R&D activities seems easier in a weak economy than raising them 20 percent. Now, 0 percent is the easiest option of them all, but unfortunately, that doesn't get us the solution to this problem.

You're saying that meeting our energy needs will be both highly complicated and fraught with unknown problems.

It is disappointing that some people have painted this problem as easy to solve. It's *not* easy, and it's bad for society if we think it is, because then funding for R&D doesn't happen.

You've talked about the need for "energy miracles." But we've been waiting for such breakthroughs for decades. TerraPower is a traveling-wave reactor, a design that dates back to the 1950s.

Well, no, we haven't been working on those things. The nuclear industry was effectively shut down in the late '70s. And so evolutionary improvements on those so-called Gen 3 designs really didn't happen, and more radical things didn't happen.

But let me get back to the main thrust of your question. The CO_2 problem is simple. Any amount you emit causes warming, because there's about a 20 percent fraction that stays for over 10,000 years. So the problem is to get essentially to zero CO_2 emissions. And that's a very hard problem, because you have sources like agriculture, rice, cows, and small sources out with the poorest people. So you better get the big sources: you better get rich-world transportation, rich-world electricity, and so on to get anywhere near your goal. If X or Y or Z gets you a 20 percent reduction in CO_2, then you've just got the planet, what, another three years? Congratulations! I mean, is that what we have in mind: to delay Armageddon for three years? Is that really it?

The U.S. uses, per person, over twice as much energy as most other rich countries. And so it's easy to say we should cut energy use through better buildings and higher MPG and all sorts of things. But even in the most optimistic case, if the U.S. is cutting its energy intensity by a factor of two, to get to European or Japanese levels, the amount of increased energy needed by poor people during that time frame will mean that there's never going to be a year where the world uses less energy. The only hope is less CO_2 per unit of energy. And no: there is no existing technology that at anywhere *near* economic levels gives us electricity with zero CO_2.

Then what kinds of energy miracles do we need?

Almost everything called renewable energy is intermittent. I have another term for it: "energy farming." In fact, you need not just a storage miracle, you need a transmission miracle, because intermittent sources are not available in an efficient form in all locations. Now, energy factories, which are hydrocarbon and nuclear energy—those things are nice. You can put a roof on them if you get bad weather. But energy farming? Good luck to you! Unfortunately, conventional energy factories emit CO_2 and that is a very tough problem to solve, and there's a huge disincentive to do research on it.

You've said that nuclear energy has the best chance of being an energy miracle.

Well, it's the one I've gotten involved in. I spend time at TerraPower. I don't claim to be the person who's surveyed all the possibilities. I think solar thermal has a lot of promise. Solar chemical: some people see the possibilities at the research level. Algae: I've actually got some money in some of those [ventures]. Then there are crazy things like these high-wind kite guys. You really don't want to rule anything out.

Will TerraPower really build a traveling-wave reactor? And if so, where?

We're in discussions with basically everybody. TerraPower itself will not raise the money to build the reactor. We will partner with some mix of sovereign and private actors to get TP1, which is what we call our first reactor, and our dream is to build that by 2020. It's more likely to be built in Asia than in North America or Europe. China's the obvious one.

TerraPower is far out.

It's very far out. It definitely needs to be categorized as a high-risk, wild thing, but the world only needs a few wild things to succeed. But you've got to get the pilot plant built, which is hard. You've got to have all the science and economics work the way they work on paper.

How has being a philanthropist broadened you in a way that your career as a software entrepreneur did not?

Believe me, when somebody's in their entrepreneurial mode—being fanatical, inventing new things—the value they're adding to the world is phenomenal. If they invent new technologies, that is an amazing thing. And they don't even have to know how it's going to help people. But it will: in education, medical research, you name it. So I was one of those fanatics in my 20s where I didn't know about poor people. I worked night and day on software. I thought a lot about software. That's a great mode to be in, but in my 30s I got exposure to management, although I was still writing some of the code. Then in my 40s, the majority of what I was doing was large-organization management and picking strategies, but I didn't write any code that shipped in products. Now, in my 50s, I'm in a role that's kind of like that. TR

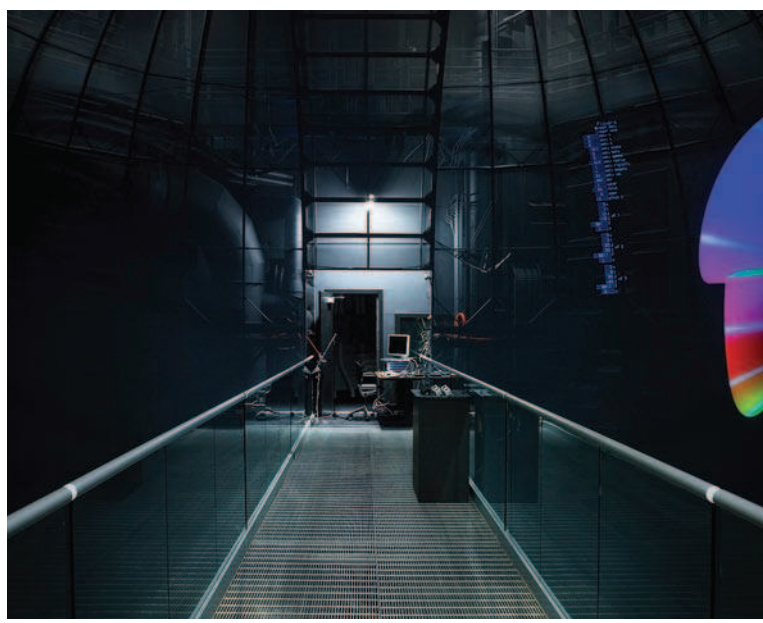
PHOTO ESSAY

LIVING DATA

Researchers pushing the furthest boundaries of science and technology can spend a lot of time contemplating the intangible. The AlloSphere, a three-story-high globe that facilitates interactive 3-D visualizations of data, is designed to help. Located at the California NanoSystems Institute at the University of California, Santa Barbara, the facility enables scientists to dive into data in unprecedented ways. Inside the sphere, they can get their hands on the atoms making up the crystal structure of new solar-cell materials or enter a brain and hear its activity.

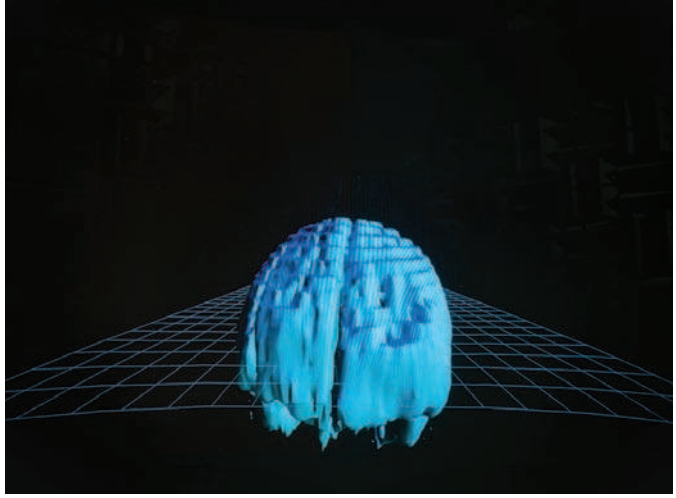
By TOM SIMONITE *Photographs by* JASON MADARA

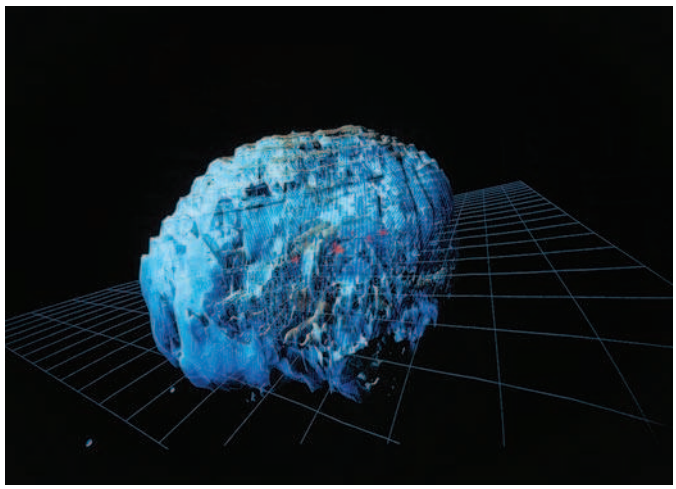
Standing on a bridge suspended across the sphere's center, a visitor contemplates a visualization of the quantum wave function of a hydrogen atom's electron. When viewed through 3-D glasses, the model appears to hang in the air.

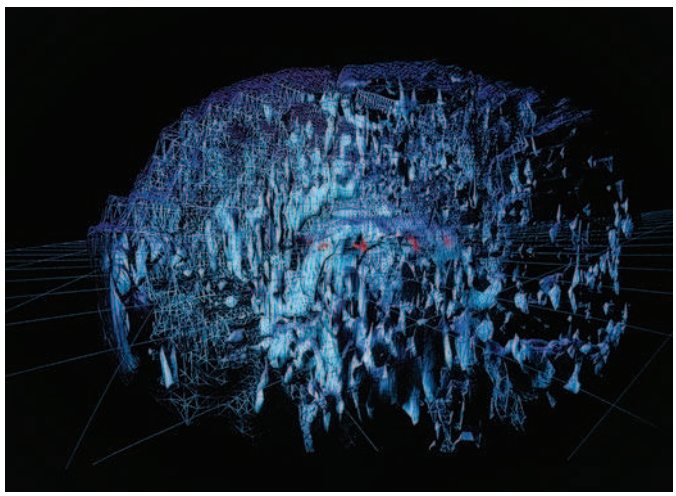


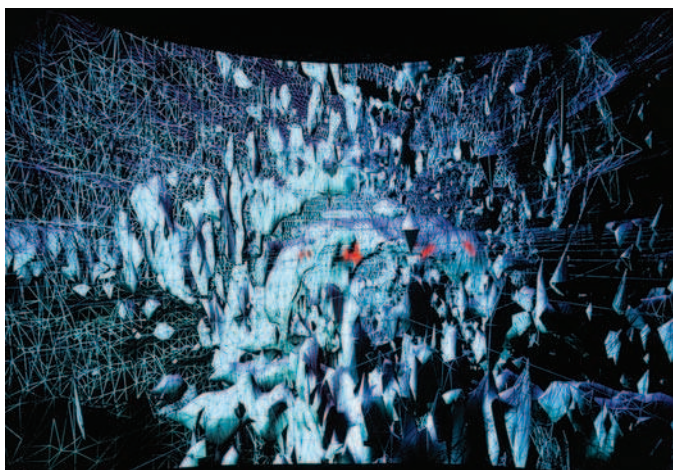
To completely immerse viewers, the AlloSphere projects visualizations of data onto the inside of two hemispheres five meters in radius (left). Viewers are suspended inside on the bridge (bottom right). "It's like being in a 30-person-capacity submarine and looking out as you move through the data," says JoAnn Kuchera-Morin, the facility's director.

The sphere itself, made of perforated aluminum, sits inside a room lined with sound-absorbing material (top right) to help 16 speakers deliver clear sound to people inside. Projectors beneath the bridge cover one side of the sphere with imagery; a recent upgrade increased the number from two to six, which can light up a broad 360° band that surrounds the viewer completely. The number of speakers is being bumped up to 128, making it possible to create soundscapes that fool the senses: sounds can seem to emanate from any point inside the sphere.

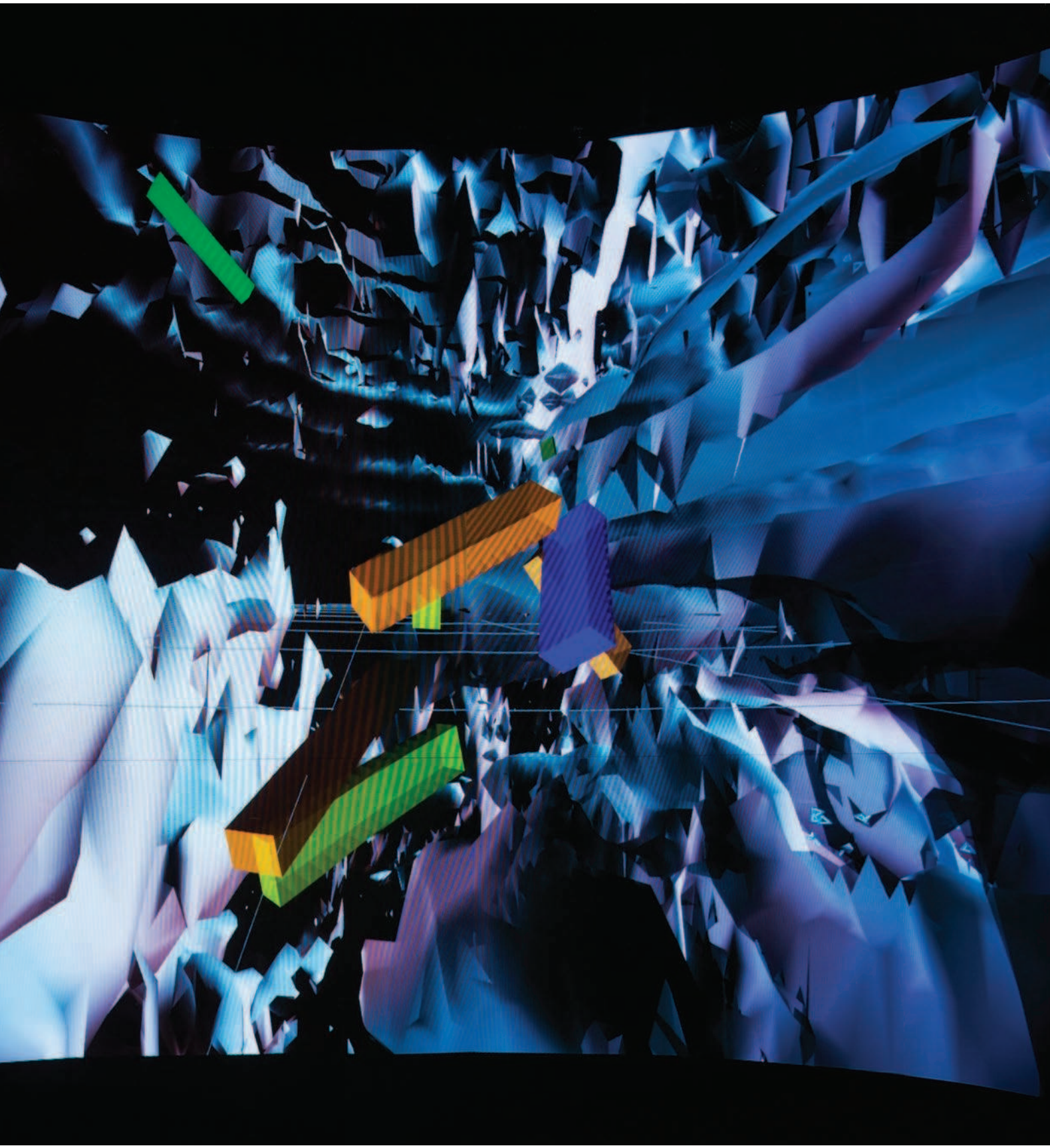


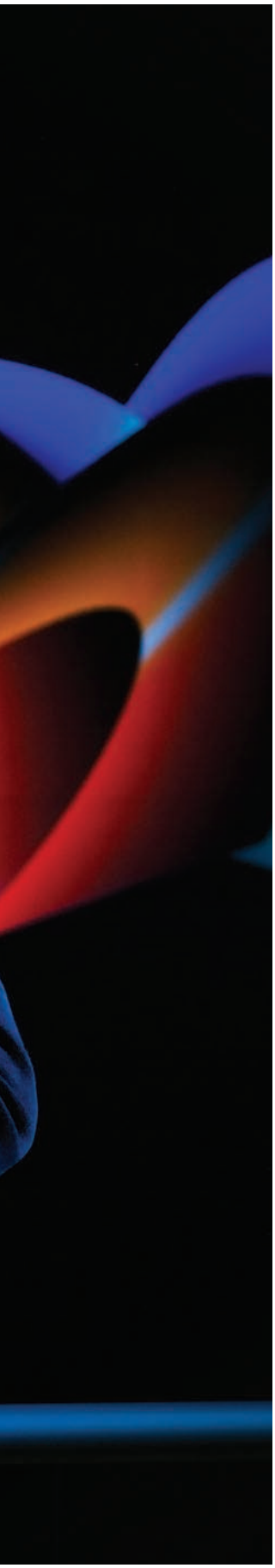






One data set being explored is a functional magnetic resonance imaging (fMRI) scan that records the activity of a brain. Navigating through the virtual 3-D space provides a novel way for neuroscientists to look at the activity in different parts of the brain during thought processes. The sequence of images at near right was taken from top to bottom as a user moved from the outside of the brain to deep inside. The interior of the brain (far right) surrounds the viewer as a vast and complex cavern, echoing with regular sounds like electronic water droplets. The colored blocks are anatomical signposts; the pitch of the droplet-like sounds correlates with the blood density at each location, a proxy for neural activity.

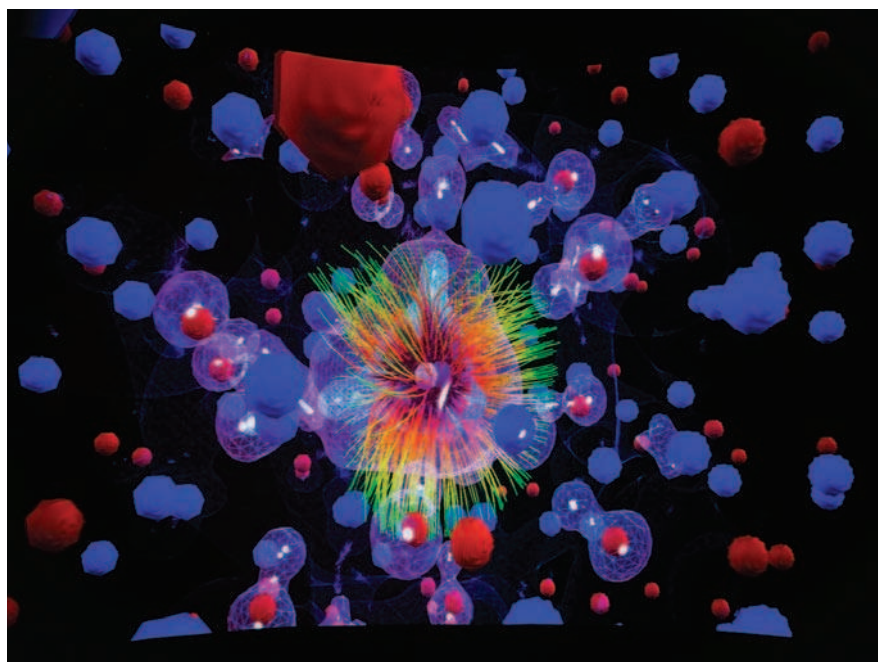


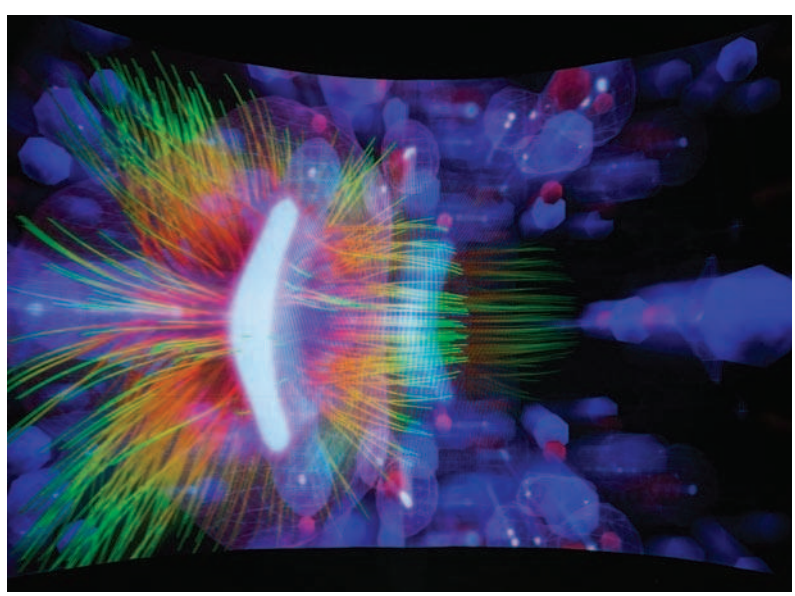


www Watch a video of the AlloSphere in action: **technologyreview.com/photoessay**

At left, computer engineer Dennis Adderton demonstrates gloves studded with infrared LEDs that are visible to 14 infrared cameras. The gloves allow users to manipulate the images using hand gestures. At right are two views of a model of a zinc-based solar-cell material. The colored streamers show how electrostatic charge density varies across a hydrogen bond; the blue and red bubbles are zinc and oxygen atoms, respectively. The same information is also translated into sound. Materials scientists have reported being able to identify bonding nodes more successfully with their ears than with their eyes, says Kuchera-Morin.

The AlloSphere's simulations could at some point be used to perform live chemistry simulations, thanks to a planned high-speed connection to the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign.





Create an application rich environment for end users.

Alcatel-Lucent understands the growing problems facing service providers. Customer demand for ever-higher bandwidth services increasingly strains networks and operating expenses, without improving the top line. Service Providers need to lower the cost of carrying video and other multimedia services while providing customers an enhanced suite of applications. Our vision for providing that environment is Application Enablement. We help Service Providers transform their business by inventing ways to combine exciting new applications with existing network capabilities to offer new services and deliver a better experience to their customers. To learn more, visit us at www.alcatel-lucent.com

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www.alcatel-lucent.com/application_enablement

35

35 INNOVATORS UNDER 35

WHO WILL BE THE NEXT HELEN GREINER, MARK ZUCKERBERG, LARRY PAGE, EVAN WILLIAMS, JONATHAN IVE, MARC ANDREESSEN, DANIEL SCHRAG, SERGEY BRIN, MAX LEVCHIN?

Each year, *Technology Review* selects 35 innovators under the age of 35 who we believe are transforming technology. We solicit candidates from around the world, looking for the best people from industry and academia. Helped by a panel of expert judges, we strive to identify those individuals who are tackling problems in a way that is likely to benefit society and business. This can mean, say, developing new materials for solar cells, but it can also mean creating new business models to commercialize technologies more efficiently. We pay special attention to those solving some of the most intractable and critical problems in the developing world. Our Humanitarian of the Year, for example, shows how software and new crowdsourcing techniques can come to people's aid in their times of greatest need. In getting to know the 2010 TR35, we have been impressed and inspired by their talent and vision; we hope you are too. —*The Editors*

35

INTERNET

Humanitarian of the Year
David Kobia, 32

Software that helps populations cope with crises

Ushahidi

The Ushahidi project brings crowdsourcing to bear on some of the most desperate situations people face around the world. Its downloadable software allows users to submit eyewitness reports during a conflict or disaster; the collected reports are displayed on a map. At times when ordinary sources of news and public information are unavailable, Ushahidi gives users a way to share information and shape political opinion, guide rescuers, or pool resources. Ushahidi has been used to monitor elections in Sudan, document violence in Gaza, track the BP oil slick, and assist earthquake recovery efforts in Haiti.

Ushahidi was born during the riots that followed Kenya's 2007 presidential election. President Mwai Kibaki had imposed a media blackout throughout the East African nation, so the Internet provided the only open channels of mass communication. David Kobia was 8,000 miles away in Birmingham, AL. A Kenyan expatriate who had dropped out of the University of Alabama at Birmingham to work as a Web developer, Kobia was frantically trying to moderate an online forum, Mashada, that had started as a personal project but was becoming a very public arena for Kenyan politics. Discussions on the site were spiraling into vitriol and paranoia. A French news agency reporting on Mashada called it Kenya's answer to Radio Mille Collines, the infamous Rwandan radio station that had fueled that country's genocide in 1994.

"Being mentioned in the same sentence as Radio Mille Collines is akin to being called a Nazi," says Kobia, a gentle man with an open face and an easy smile. Beset by remorse and despair, he pulled the plug on Mashada, got into his car, and sped up Interstate 20, planning to spend a somber winter holiday with friends in Atlanta. Somewhere near the Georgia border, his cell phone rang. An online acquaintance, Erik Hersman, was calling. Hersman had read a post by a prominent Kenyan blogger, Ory Okolloh, calling for someone with the know-how to program a Google map to track the violence and destruction. "Can you put it together?" Hersman asked. Seeing an opportunity to atone for Mashada, Kobia turned around and headed back to Birmingham. Two days later, Ushahidi was up and running.

That initial version was simple: just a map and a form that let users describe an incident, select the nearest town, and note the location, date, and time. Nonetheless, it was enough to attract widespread attention. "Suddenly my phone was ringing off the hook to do an interview with BBC News or NPR," Kobia says.

By now, Ushahidi—the name means "testimony" in Swahili—has played a central role in coördinating the responses to crises around the globe. Kobia, with the help of Hersman, Okolloh, program director Juliana Rotich, and a growing number of coders, has continued to develop and expand the original no-frills online application into a downloadable open-source platform that includes a time line, an API to develop applications for mobile devices, an architecture that allows functionality to be added through software plug-ins, and support for several mapping protocols. It has been used in more than 30 countries, mostly by grassroots relief and watchdog organizations, to direct aid workers to specific locations, document corruption, and track complex events in space and time.

"Ushahidi is one of the most globally significant technology projects," says Ethan Zuckerman, cofounder of the blog network Global Voices and a senior researcher at Harvard's Berkman Center for Internet and Society. "It's built on open standards and accepts input not only from the Web but from mobile devices—a critical feature for enabling global participation. And it evolves with each installation, resulting in a system that can aggregate, map, and authenticate crowdsourced data in a very wide range of environments."

REDEMPTION

Kobia grew up in Kenya, the son of a civil engineer and a schoolteacher. He moved to America to study computer science at the University of Alabama in 1998. By that time, the dot-com boom was under way, and Kobia left school to build publishing platforms for Time Inc., *Reader's Digest*, and Cygnus Publications and also for sites that automated processes such as hiring or booking travel. Through those projects, he gained the deep knowledge of online infrastructure that made it possible for him to assemble the first version of Ushahidi so quickly.

YVONNE BOYD

LONG REACH
David Kobia's Web programming helps communities facing catastrophe around the world.

Soon after Ushahidi came online, Kobia was contacted by NetSquared, a nonprofit that promotes the Web as a vehicle for social change. The organizers invited the Ushahidi team to enter its Mashup Challenge, and Kobia flew to San Jose, CA. Walking among the gathered Silicon Valley hipsters, he thought that a group of Africans had little chance. To his great surprise, Ushahidi won the competition. It was a triumphant moment for Kobia, who still felt lingering guilt for the Mashada forum. "I felt drunk with redemption," he says.

Returning to Birmingham, Kobia wrapped up his business and threw himself into Ushahidi, funded by $25,000 from NetSquared and a grant from Humanity United. Later, he secured some $700,000 from philanthropies including the Cisco, Knight, and MacArthur foundations. The result is a system that packs tremendous communication power into a simple user interface. The platform collects incident reports through e-mail, status updates, and blog posts; reports can include text, photos, audio, and video. It uses another open-source program, FrontlineSMS, to aggregate text messages, making good use of the cell phones that are ubiquitous in the developing world even where computers are rare.

> **"Ushahidi is one of the most globally significant technology projects."**
> **—Ethan Zuckerman**

Incoming incident reports queue up on a dashboard screen where administrators—usually volunteers for organizations that have downloaded Ushahidi and set it up on a server—can categorize and vet them by cross-checking against news and other information online. Within minutes of arrival, messages deemed valid are posted to a public Web page, where they appear on a map as colored dots that grow as reports from those locations accumulate.

HELPING HAITI

After receiving the NetSquared prize, Ushahidi played a role in crisis after crisis as tech-savvy grassroots organizations downloaded the platform. With each implementation, it grew as users requested features and Kobia and a growing team of developers obliged. The most challenging test came early this year. On the evening of January 12, 2010, Kobia received an urgent phone call from Patrick Meier, director of crisis mapping and strategic partnerships at Ushahidi and founder of the International Network of Crisis Mappers, an Internet-based group that brings together cartographers, imaging experts, and specialists in crisis management. He was looking for ways that digital mapping might help Haiti cope with the aftermath of the earthquake that had just struck.

Kobia set up a Ushahidi website for the crisis, and within hours, the system was fielding reports of human misery on a vast scale—25,000 text messages and 4,500,000 Twitter posts before the month

2010 TR35 Judges

Ed Boyden*
Leader, Synthetic Neurobiology group, MIT

George Church
Professor of genetics, Harvard Medical School

James J. Collins*
Professor of biomedical engineering, Boston University

Yi Cui*
Associate professor of materials science and engineering, Stanford University

David Culler
Professor of computer science, University of California, Berkeley

Mildred S. Dresselhaus
Professor of physics and electrical engineering, MIT

Stephen H. Friend
CEO, Sage Bionetworks

Kevin Fu*
Assistant professor of computer science, University of Massachusetts, Amherst

Javier García-Martínez*
Professor of inorganic chemistry, University of Alicante

Scott Heiferman*
CEO, Meetup

Eric Horvitz
Principal researcher, Microsoft Research

Phil Janson
Adjunct professor, École Polytechnique Fédérale de Lausanne

Ed Lazowska
Professor of computer science, University of Washington

Johnny Chung Lee*
Researcher, Microsoft

Nick McKeown
Professor of electrical engineering and computer science, Stanford University

Christopher B. Murray*
Professor of chemistry, materials science, and engineering, University of Pennsylvania

Krishna V. Palem
Professor of computer science, Rice University

Stephen Quake*
Professor of bioengineering, Stanford University

Prabhakar Raghavan
Head of research, Yahoo Labs

Nimmi Ramanujam*
Associate professor of biomedical engineering, Duke University

Dipankar Raychaudhuri
Professor of communications, Rutgers University

John Rogers*
Professor of engineering, University of Illinois at Urbana-Champaign

Chris R. Somerville
Director, Energy Biosciences Institute, University of California, Berkeley

Bjarne Stroustrup
Professor of computer science, Texas A&M University

Susie Wee*
CTO, Client Cloud Services, Hewlett-Packard

Jennifer West*
Professor of bioengineering, Rice University

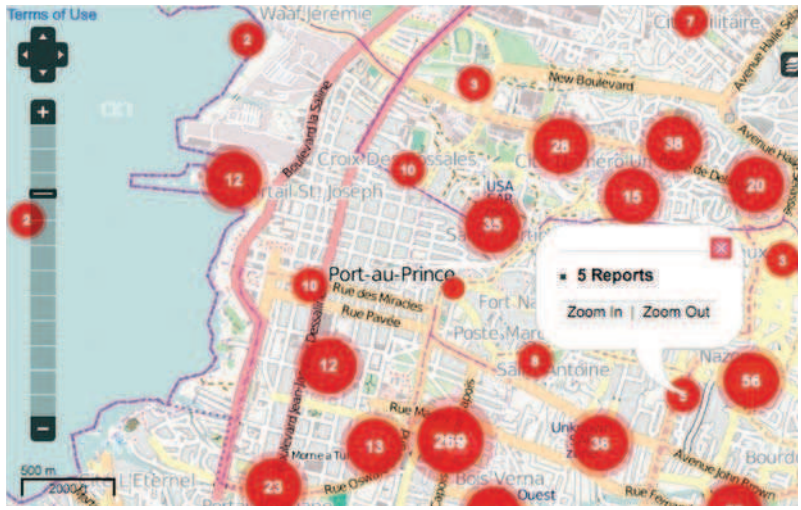
John Wiss
Adjunct professor of mechanical engineering, Carnegie Mellon University

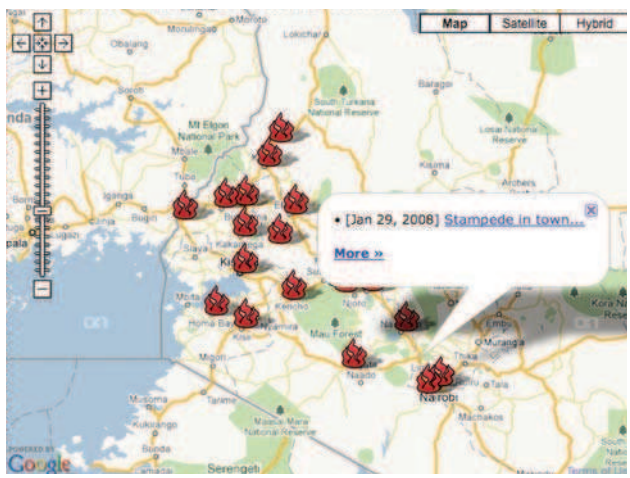
Jackie Ying*
Director, Institute of Bioengineering and Nanotechnology

Ben Y. Zhao*
Associate professor of computer science, University of California, Santa Barbara

Victor Zue
Professor of electrical engineering and computer science, MIT

**Past TR100/TR35 honoree*





GROUND TRUTH Ushahidi helped coördinate responses to the 2010 Haitian earthquake (above, and mapped at top right). The system grew out of the response to a disputed Kenyan election in 2007 (mapped at bottom right).

was out. Working through the U.S. State Department, he arranged with Haitian telecommunications companies to supply a four-digit SMS code for emergency messages. Aid workers in Haiti distributed the number on printed flyers.

The bulk of incoming incident reports were written in Creole, so Ushahidi arranged for some 10,000 Haitian expatriates in North America to serve as translators, first through a custom system and later through a partnership with the commercial crowdsourcing website CrowdFlower. Meanwhile, Meier organized Tufts University students to log reports around the clock. First responders, including members of the U.S. military, used Ushahidi's map to set priorities, organize, and reach distressed people.

Ushahidi had a decisive impact on the Haitian crisis—and vice versa. On the one hand, Kobia was thrilled to see the system rise to the occasion. On the other, the effort almost drove his team into the ground. "We put in 20-hour days for a month," he says. "Developers were getting burned out." He realized that the organization was failing in its goal of giving others the ability to use the platform independently.

Since then, Kobia has focused much of his energy on making Ushahidi more accessible and easier to operate. For instance, an initiative called Crowdmap delivers Ushahidi's functionality directly over the Web, so local groups don't have to install it on servers of their own. He's also working on a system that uses machine learning and natural-language processing to evaluate the validity of incoming data.

Some of these efforts might ultimately generate revenue: larger organizations might pay for Crowdmap's services or license other parts of the Ushahidi technology. This is necessary, Kobia says, to insulate Ushahidi from the whims of charity, about which he is deeply ambivalent. "In truth, I don't like nonprofits," he says. "They've never solved any problems. Instead, they've destroyed free enterprise and turned Africans into beggars. Some of the best programmers in Kenya are working for nonprofits when they could be creating an economy. Ushahidi's challenge is not to get caught in that cycle."

To that end, Kobia has started an innovation center meant to galvanize Nairobi's burgeoning high-tech community. "There's a pool of mind-blowing talent waiting to be tapped," he says. "We remind them, 'It's your duty to participate in this community and build your own businesses.'" —*Ted Greenwald*

PHOTO: CHESNOT/SIPA/ASSOCIATED PRESS; SCREENSHOTS: USHAHIDI

SOCIAL SLEUTH
Danah Boyd is uncovering the unexpected effects of networking sites.

MARK OSTOW

INTERNET

Danah Boyd, 32

Shaping the rules for social networks

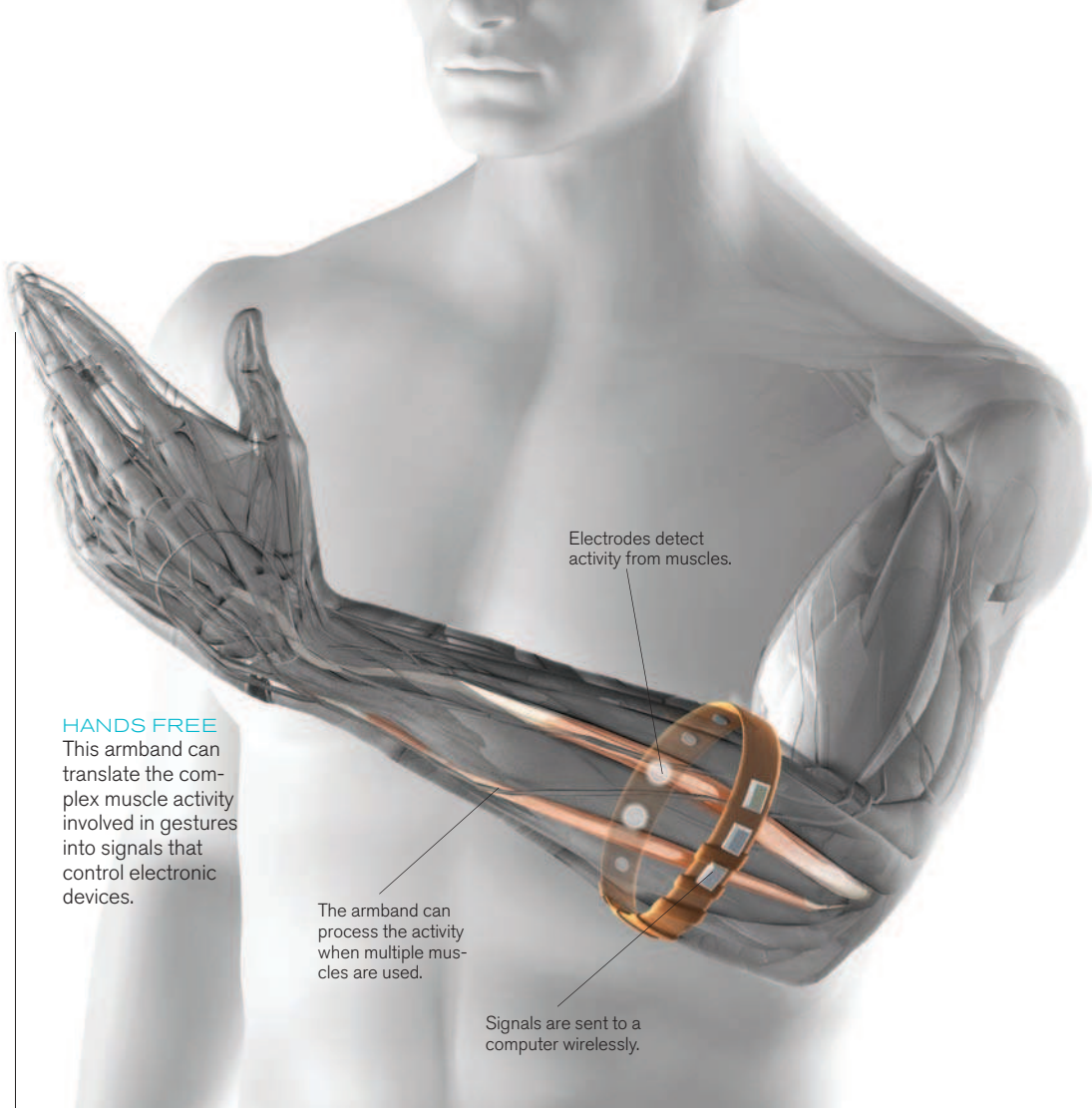
Microsoft Research

AS MORE and more people join social-networking sites, Danah Boyd is asking and answering some uncomfortable questions about these online communities. Among other things, she has detailed how race has been a factor in some users' migration from MySpace to Facebook, how social networks are changing the way teenagers relate to one another, and how the Internet alters the way people think about privacy.

Working as an advisor, Boyd has shaped the policies of companies like Google and LiveJournal. Now employed by Microsoft Research New England, she has been talking with government regulators and privacy advocacy groups to determine how best to help users protect their personal information. She believes that privacy regulation is inevitable and is trying to guide the industry and regulators toward a set of mutually acceptable rules.

Critical to any such solution, Boyd says, is making sure that people can control what happens to their personal data after it has been entered into a social network.

—Erica Naone



HANDS FREE
This armband can translate the complex muscle activity involved in gestures into signals that control electronic devices.

BRYAN CHRISTIE DESIGN

HARDWARE

T. Scott Saponas, 29

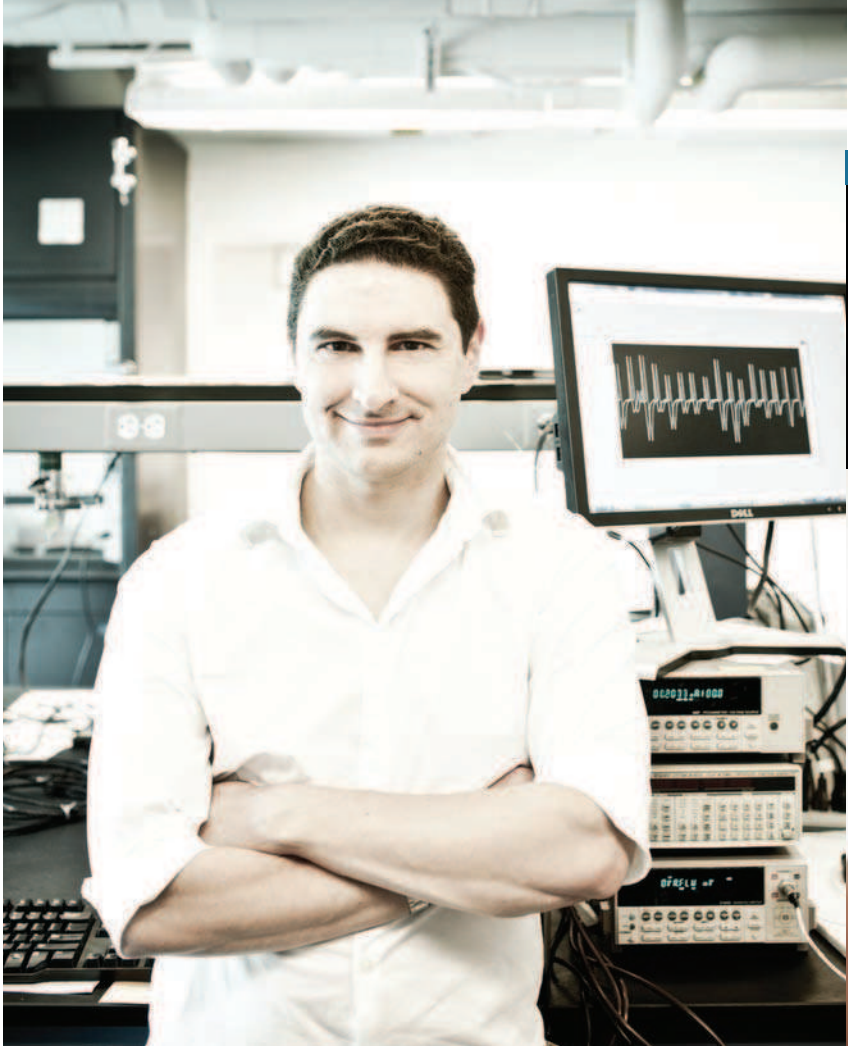
Detecting complex gestures with an armband interface

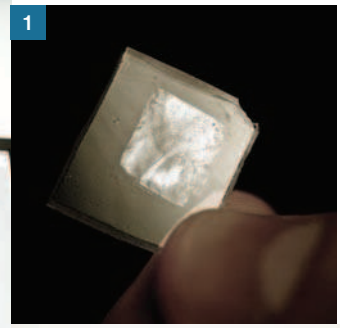
Microsoft Research

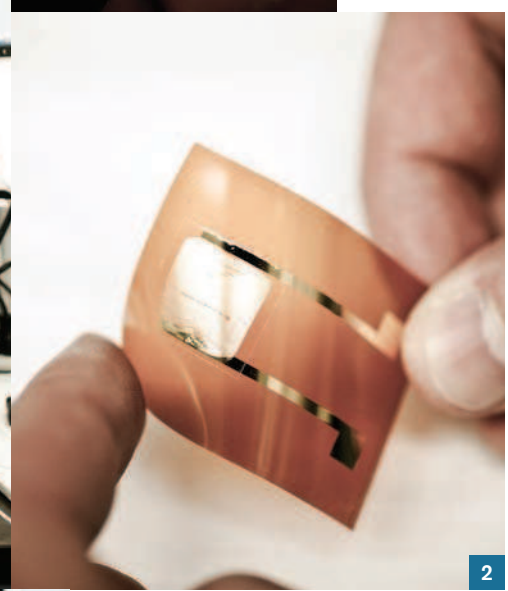
Fingers flicking through the air, T. Scott Saponas is rocking a solo in the video game Guitar Hero—without a guitar. A soft band around his forearm monitors the muscles moving his fingers and hand. The band hides a ring of six electrodes that pick up the weak electrical signals produced by active muscle tissue. The signals are relayed to a computer, which in turn controls the game.

Most previous work on muscle interfaces has focused on controlling broad movements of prosthetic limbs by detecting the activity of individual muscles. To recognize more detailed gestures, Saponas developed software capable of processing the jumble of signals from the mass of muscles in the arm. The system has potential for more than just video games. A jogger using Saponas's armband could tense his or her hand muscles to switch tracks on an MP3 player without breaking stride, or a mechanic whose hands were busy inside an engine could use it to control a heads-up display.

Saponas created the software as a graduate student at the University of Washington. Now working at Microsoft Research, he is interested in combining the muscle interface with other sensors, including accelerometers and gyroscopes, to provide additional precision. *—Tom Simonite*







STRESS TEST Michael McAlpine sandwiches ribbons of PZT between layers of silicone or plastic (1) and then attaches leads (2) to make a flexible device that generates electricity when bent (3). These devices might one day power pacemakers or other implanted devices, bending back and forth as a patient's lungs inflate and deflate.

RYAN DONNELL

MATERIALS

Michael McAlpine, 32

Powering electronics with human motion

Princeton University

Michael McAlpine has developed a flexible material that produces record amounts of energy when subjected to mechanical pressure. It could turn the action of a patient's lungs into enough energy to power an implanted medical device; forces produced by walking around could be sufficient to drive portable electronics.

In 2008, as a new assistant professor at Princeton, McAlpine started thinking about pacemakers: was there a way to harvest power from the lungs as people inhaled and exhaled, so that the batteries wouldn't need to be surgically replaced every few years? Drawing on previous experience in making nanowire electronics and sensors on sheets of plastic, McAlpine began experimenting with PZT, a well-known material that is piezoelectric—able to convert physical stress into electricity. To make a flexible device, he deposits the PZT onto a hard substrate before carving the material into tiny ribbons. Then he uses chemicals to release the ribbons of PZT from the substrate and transfers them to a piece of silicone. A second piece of silicone seals the PZT in, creating a pliable, biocompatible material that's four times as efficient as previous flexible piezoelectrics. So far McAlpine has made only small pieces of the material, but he is now scaling up the process to make larger wafers suitable for use in implanted electronics. *—Katherine Bourzac*

TELECOMMUNICATIONS

Amir Alexander Hasson, 34

Using cell phones to supply rural shop owners

United Villages

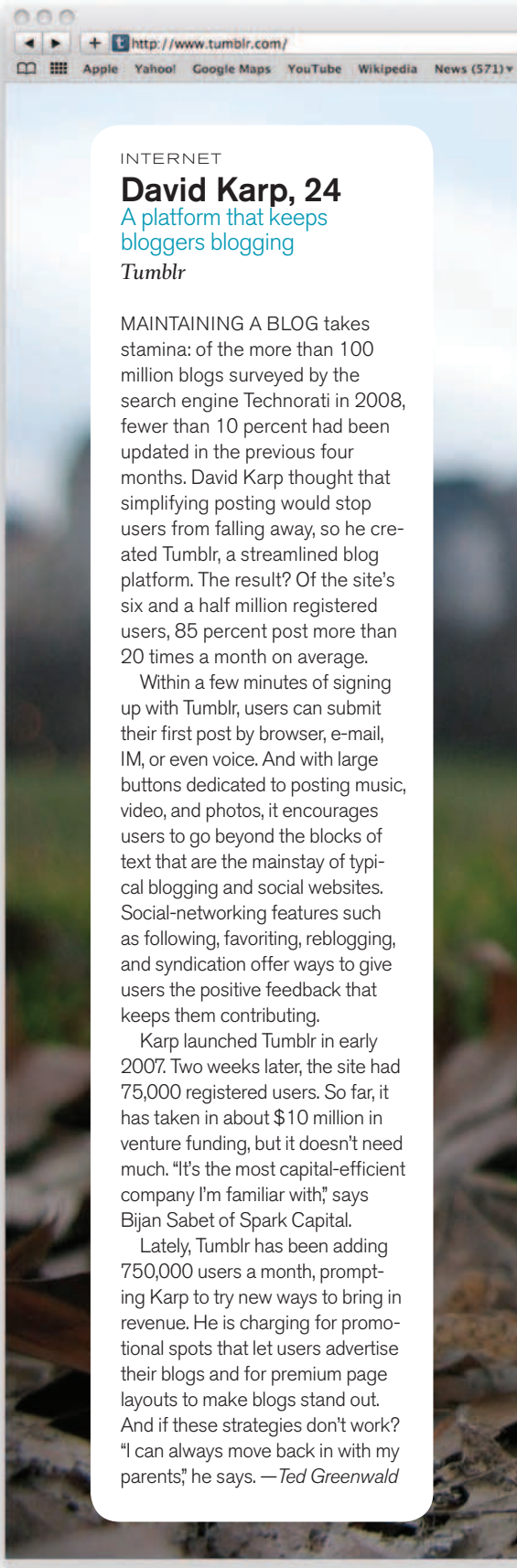
Many shop owners in Indian villages are beyond the reach of major distributors. Some goods are sold to them by local producers, but owners "have to leave their shops four times a month to get 81 percent of the stuff that they sell," says Amir Alexander Hasson. Having to travel to restock doesn't just affect shop owners; villagers end up paying higher prices for a smaller selection of goods. Since founding United Villages in 2004, Hasson has been using wireless technologies to help solve this and other problems facing the rural poor in developing nations.

Hasson started out with a system that helped people in isolated communities send and receive e-mail and search for jobs. Wi-Fi routers were attached to buses; when a bus drove into a village, its router connected with computers set up at local kiosks. Now Hasson is taking advantage of the rapid expansion of cell-phone networks to set up a for-profit wholesale service called E-Shop. Shop owners with phones that run Java applications can browse an online catalogue and place orders; data is transferred between the phones and United Villages using SMS text messages. This method is cheap and doesn't require powerful smart phones. In about 36 hours, the goods are delivered directly to the shop.

Hasson is planning to introduce another use of E-Shop, as a way for people to post advertisements through a local store owner. "For [50 cents], someone can post his motorbike for sale," says Hasson, "It will be India's first mobile-based classifieds." —*Nidhi Subbaraman*

KIOSK CONNECTION United Villages brings the benefits of wireless technology to the rural poor through local shop owners.

UNITED VILLAGES



INTERNET

David Karp, 24

A platform that keeps bloggers blogging

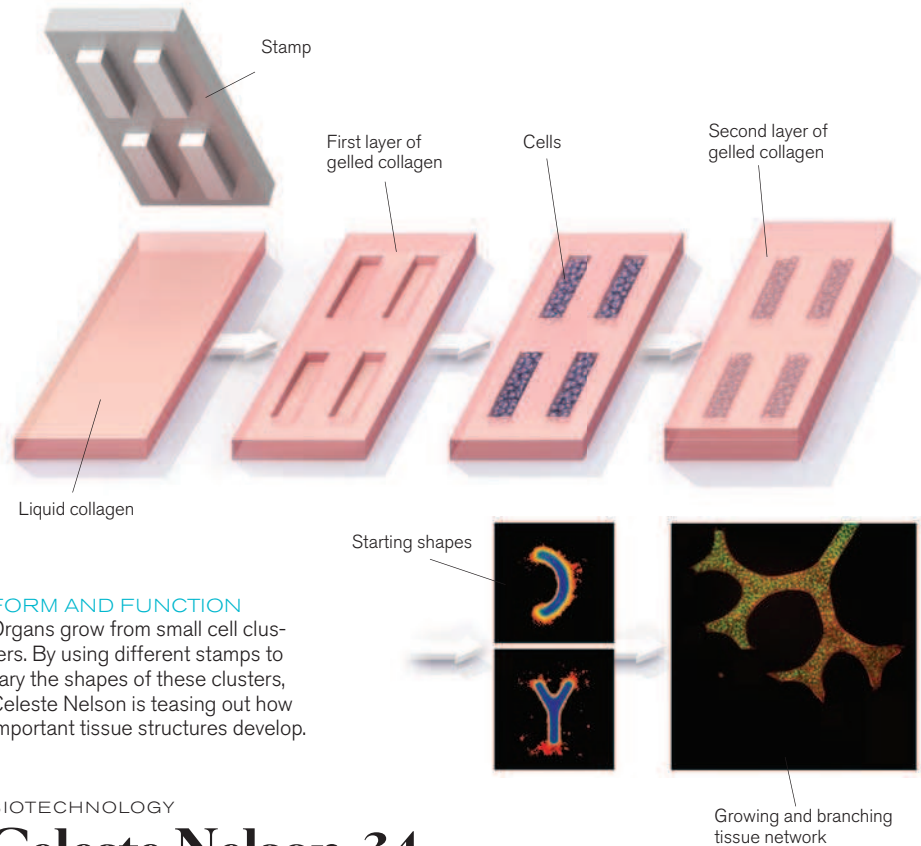
Tumblr

MAINTAINING A BLOG takes stamina: of the more than 100 million blogs surveyed by the search engine Technorati in 2008, fewer than 10 percent had been updated in the previous four months. David Karp thought that simplifying posting would stop users from falling away, so he created Tumblr, a streamlined blog platform. The result? Of the site's six and a half million registered users, 85 percent post more than 20 times a month on average.

Within a few minutes of signing up with Tumblr, users can submit their first post by browser, e-mail, IM, or even voice. And with large buttons dedicated to posting music, video, and photos, it encourages users to go beyond the blocks of text that are the mainstay of typical blogging and social websites. Social-networking features such as following, favoriting, reblogging, and syndication offer ways to give users the positive feedback that keeps them contributing.

Karp launched Tumblr in early 2007. Two weeks later, the site had 75,000 registered users. So far, it has taken in about $10 million in venture funding, but it doesn't need much. "It's the most capital-efficient company I'm familiar with," says Bijan Sabet of Spark Capital.

Lately, Tumblr has been adding 750,000 users a month, prompting Karp to try new ways to bring in revenue. He is charging for promotional spots that let users advertise their blogs and for premium page layouts to make blogs stand out. And if these strategies don't work? "I can always move back in with my parents," he says. —*Ted Greenwald*



FORM AND FUNCTION
Organs grow from small cell clusters. By using different stamps to vary the shapes of these clusters, Celeste Nelson is teasing out how important tissue structures develop.

BIOTECHNOLOGY

Celeste Nelson, 34

Reconstructing tissue architectures from scratch

Princeton University

How do organs such as the lungs or kidneys generate the intricate, treelike internal anatomy essential to their function? To find out, Celeste Nelson developed a lab technique for growing structures from simple shapes like the ones from which organs begin developing in the embryo. Nelson knew, for example, that lungs begin as an inverted Y. By experimenting with different shapes, such as a T instead of a Y, she discovered that the exact form of these initial structures plays a pivotal role in how the tissue's sophisticated architecture develops. Different starting shapes produce different patterns and concentrations of signaling molecules. The molecules cause growing branches to repel each other. Subsequent mechanical stresses in the branches determine where new branches will begin to develop and, in turn, produce their own signaling molecules. Other researchers had previously theorized that geometry matters in tissue development. But Nelson's technique—adapted from a process originally used to make computer chips—allowed her to prove it for the first time, and to spell out the mechanism involved.

Nelson, now an assistant professor of chemical engineering at Princeton, has worked with her group to identify several genes that need to be present and functional for branching tissue to develop properly, and they are trying to figure out how those genes work together to orchestrate the process. She hopes that understanding how branching normally happens will reveal ways to intervene when it goes awry. Recent work has shown, for example, that the signals that spur branching—which are typically silent once development is complete—are reawakened in some tumors. In addition, her techniques for building three-dimensional tissue structures could ultimately be used to help engineer replacement organs. *—Jocelyn Rice*

HARDWARE

Aaron Dollar, 32

Creating flexible robotic hands

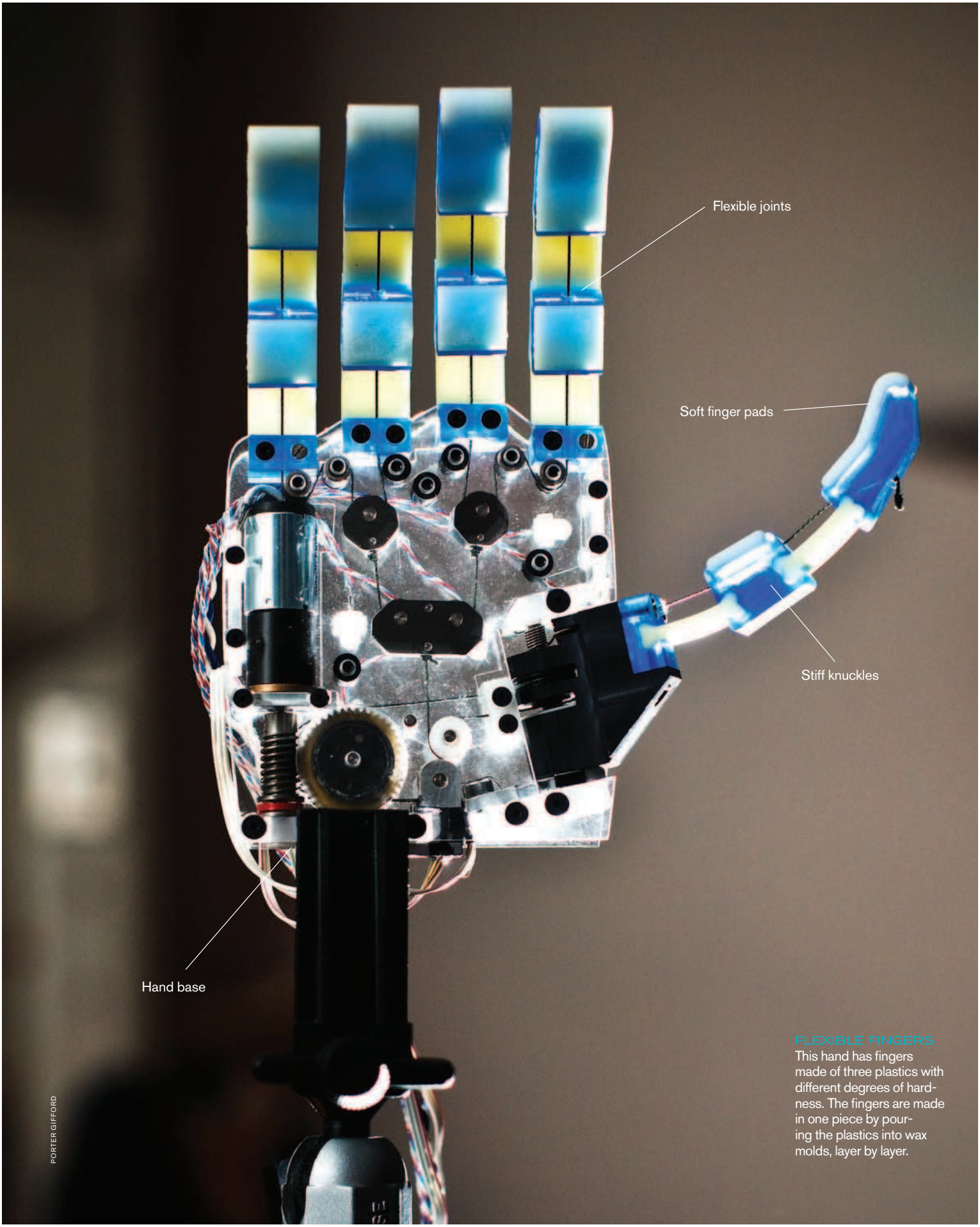
Yale University

AARON DOLLAR, an assistant professor of mechanical engineering at Yale, has invented a robot with a soft touch. His plastic hand is deft enough to grasp a wide variety of objects without damaging them. What's more, it's cheaper and requires less processing power than the metal hands typically used in robots.

Dollar's design uses plastic fingers that can lightly brush against an object—whether it's a wine glass, beach ball, or telephone—before firming up their grip. Few researchers have used soft plastic in robotics before, partly because it can be difficult to shape small, precise parts out of such materials. To get around this problem, Dollar mills wax molds for each finger. He places sensors and cables in the molds and then pours in layers of three types of plastic with varying degrees of softness—for fingers, joints, and finger pads. Once the plastics harden and are removed from the molds, the fingers are ready to be hooked up to a base. Dollar's design has already been licensed to one robotics manufacturer, and because it replicates the flexibility and gentleness of a human hand, he is investigating whether it could work as a prosthetic.

—Kristina Grifantini

EMILY COOPER



PORTER GIFFORD

FLEXIBLE FINGERS
This hand has fingers made of three plastics with different degrees of hardness. The fingers are made in one piece by pouring the plastics into wax molds, layer by layer.

MIX AND MATCH Aviary's cloud-based Web applications allow users to mix and match elements from their creations, creating derivative works that can be shared in turn.

INTERNET

Avi Muchnick, 31

Cloud-based multimedia editing software

Aviary

"EVERYONE wants to be an artist," says Avi Muchnick, sitting amid the clutter of his startup's new Manhattan headquarters. Muchnick's company, Aviary, makes free Web-based software for creating and editing images and sounds. Users can do everything from tweaking photographs to composing complex multitrack musical arrangements.

Aviary's tools aren't as powerful as commercial applications like Adobe Photoshop, an expensive photo editing program that professionals use. But because all user data is stored on a cloud-computing platform, users can easily share not just finished works but all the individual elements that went into a work; if someone creates a graphic of a teacup for a poster about a public reading of *Alice in Wonderland*, someone else can extract that graphic and use it in a logo for a café. Aviary tracks how and where elements are used, making sure that licenses and credits are preserved. Ultimately, the company hopes to create a marketplace where creators can charge royalties for their work, with Aviary taking a cut. Since the company was founded in 2007, Muchnick has raised $11 million in venture capital and angel funding from investors such as Amazon founder Jeff Bezos. —*Stephen Cass*

COURTESY OF AVIARY

ENERGY

Chris Rivest, 28

Printing cheaper solar cells

SunPrint

The lowest-cost solar panels on the market are made using thin-film solar cells that cost about 80 cents per watt of electricity they produce; costs for other types of cells can be as high as $2 per watt. Those prices are too high if solar power is to displace coal and natural gas. But Chris Rivest has a plan to reduce the price of solar cells to well under 50 cents per watt.

Rivest cofounded SunPrint in 2008 to build cheaper solar cells using a process called acoustic printing, originally developed by Xerox for ink-jet printers. Focusing a sound wave onto a pool of ink causes droplets to spatter onto a nearby surface. Rivest and his cofounders designed and built an acoustic printer to deposit layers of ink containing cadmium telluride, one of the most cost-effective solar-cell materials available, on glass, plastic, or metal. Because acoustic printing provides finer control than other printing methods, the technique uses 50 percent less cadmium telluride and eliminates further processing steps that require expensive tools. Rivest expects commercial production of solar panels to begin within a year or so. *—Neil Savage*

SOLAR SELLER Acoustic printing could make solar cells less expensive.

TOBY BURDITT (RIVEST); FEAMSTER??

INTERNET

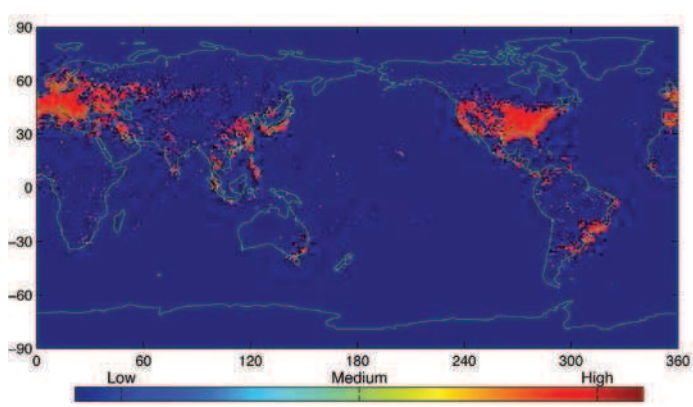
Nick Feamster, 31

Watching the suspicious behavior of spam

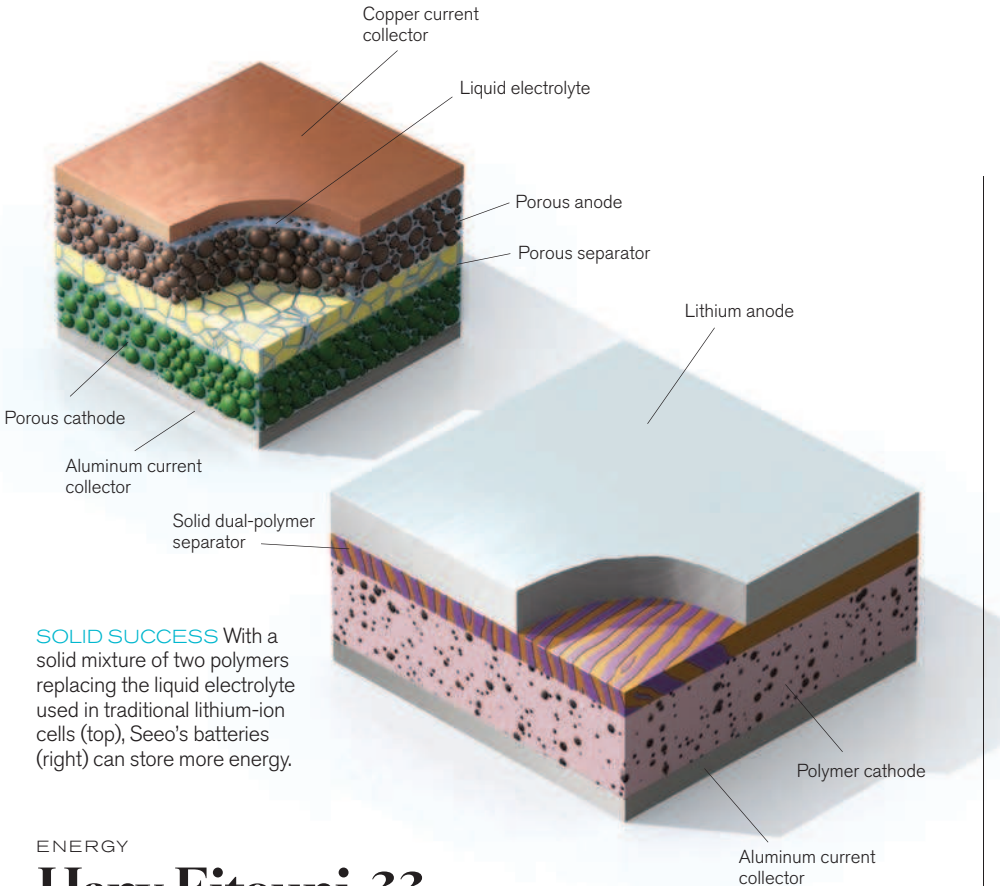
Georgia Tech

FOR YEARS, e-mail providers, IT departments, and network operators have fought spam with the help of technology that examines what messages say. Nick Feamster, an assistant professor at Georgia Tech, had a better idea. Instead of examining content, he looks at how messages move through networks, on the theory that the traffic flow of legitimate messages and spam should be different.

For example, Feamster found that spammers often try to hide in "dark space"—normally unconnected Internet addresses. Suddenly, a previously unreachable block of addresses would light up, send out a bunch of messages, and then disappear. Watching for phantom networks that appear for 10 minutes at a time turned out to be one way to identify and stop spam. His strategies have been adopted by companies such as Yahoo and McAfee in their ongoing struggle to prevent spam from reaching users. *—Erica Naone*



GLOBAL GUNK Nick Feamster's research team tracks the regions of the world most afflicted by spam.



SOLID SUCCESS With a solid mixture of two polymers replacing the liquid electrolyte used in traditional lithium-ion cells (top), Seeo's batteries (right) can store more energy.

ENERGY

Hany Eitouni, 33

Making safer batteries with solid polymers

Seeo

Hany Eitouni has built batteries that are safer, longer-lasting, and able to store more energy in a smaller space than the conventional lithium-ion cells commonly used today. His technology, Eitouni says, could be used in next-generation electric cars and even in the electric grid, which would be a new application for lithium-ion batteries.

While working at the Lawrence Berkeley National Lab, Eitouni figured out how to replace the most dangerous component of lithium-ion batteries: a flammable liquid electrolyte that conducts electricity between the positive and negative electrodes. The more energy packed into a battery, the higher the danger that the liquid electrolyte will catch fire. Previous researchers had tried to sidestep this problem by using gel polymers for the electrolyte, but even these contained flammable solvents.

The solution was a solid material that is made of two linked polymer chains. One polymer is almost as conductive as a traditional liquid electrolyte but a lot less flammable; the other, which is also less flammable, provides mechanical stability so that the electrolyte doesn't turn into goo. And the battery lasts longer than traditional lithium-ion or previous lithium-polymer cells because the polymer doesn't react with the charged electrodes.

To commercialize the technology, Eitouni cofounded Seeo in Berkeley, CA, in 2007. He says that the startup's battery keeps 90 percent of its storage capacity after 2,000 charges (traditional rechargeable batteries lose nearly a third of their capacity after about 500 charges). It also stores 50 percent more energy per kilogram than commercial lithium-ion batteries. Seeo is building a pilot factory that will make large battery packs to smooth out spikes in supply and demand on the electric grid. It's expected to be completed in 2011. *—Kate Greene*

INTERNET

Wesley Chan, 32

Building new technology businesses

Google

WESLEY CHAN has a knack for turning good ideas into new businesses—and doing it with minimal resources. In 2005, Chan's small team at Google, which incorporated two start-ups he acquired for the company, launched Google Analytics to provide a free version of the tools the search giant previously used internally. In 2006, he dreamed up another free service, Google Voice, which launched in 2009. This one offers automatic transcription of voice mail, the ability to use one number for different phones, and many other features. Given only two company engineers to work with on the project, Chan acquired the startup GrandCentral in 2007; he and his new crew spent the next two years putting the service together in secret.

Google Voice now has millions of users. But Chan has moved on again and is now a partner at Google's venture capital investment group, Google Ventures. He still invests in software but is free to cast his net wider. In particular, he is developing an interest in stem-cell medicine, even though the field has no direct connection to Google's business. He says, "For me it's about going where I can learn the most, and making the output of my learning something that is world-changing." *—Tom Simonite*

EMILY COOPER

THE COACH At Google, Wesley Chan displayed a knack for building teams to fill technology niches.

TOBY BURDITT

SOFTWARE

Richard Tibbetts, 30

Reacting to large amounts of data in real time

StreamBase Systems

ORGANIZATIONS SUCH as businesses and governments are increasingly obsessed with gathering data, but the results often overwhelm them when they need to act quickly. Richard Tibbetts, CTO of StreamBase Systems in Lexington, MA, has developed a data processing system that can accept large amounts of rapidly changing input and distill it into the information that organizations feel they need to make sound decisions.

Traditionally, organizations have turned to databases to store and manipulate large amounts of information. Typically, however, these databases aren't good at processing data in real time; users have to wait until an entire data set has been accumulated. But Tibbetts has invented a new set of techniques for managing data. In particular, he invented a language called StreamSQL EventFlow, which can process a stream of data as it arrives, analyze it, make decisions about it, and take actions such as trading a stock or flagging a trend.

StreamBase counts government agencies, investment banks, and hedge funds among its clients. The technology has been used to monitor activity on battlefields as combat unfolds and to help businesses react as stock market conditions change. —*Erica Naone*

JESSICA SCRANTON

BIOTECHNOLOGY

Mikhail Shapiro, 29

Commercializing neurotechnology

Third Rock Ventures

Who better to determine which fledgling technologies should form the basis of new venture-backed biotech companies than someone who's helped develop significant new neurotechnologies and has firsthand experience with launching a revolutionary startup? In 2001, Mikhail Shapiro, still a sophomore at Brown University, cofounded a company called Cyberkinetics to develop implantable devices that would allow quadriplegics to control external devices with their thoughts. Shapiro, then 20, ran the business side of the company and helped raise its first $20 million in venture funding, which led to groundbreaking clinical trials. "His knowledge of the business world even at that young age was frightening," says cofounder John Donoghue, a professor of neuroscience and engineering at Brown, who was chief scientific officer of the startup. Though Cyberkinetics has since folded, the results of its pilot trials proved that this type of technology could work, and they brought new funding and interest to the field.

Shapiro then earned a PhD at MIT, where he developed a noninvasive imaging technology for observing chemical messengers in the brain. Since joining Third Rock Ventures in 2008, he has led the venture capital firm's efforts to evaluate neurotechnologies such as optogenetics, a method of controlling the brain with light. So far he has helped found two more companies, with combined funding of $50 million. One is focused on a new pain drug and the other on using personalized medicine to fight cancer. —*Emily Singer*

DIAGNOSTIC DEVICE
Made using plastic injection molding, this microfluidic chip is inexpensive to produce. Small amounts of reagents and a fluid sample from a patient are guided through its tiny channels to test for STDs.

BIOTECHNOLOGY

Samuel Sia, 34

Inexpensive microfluidic chips for diagnostics

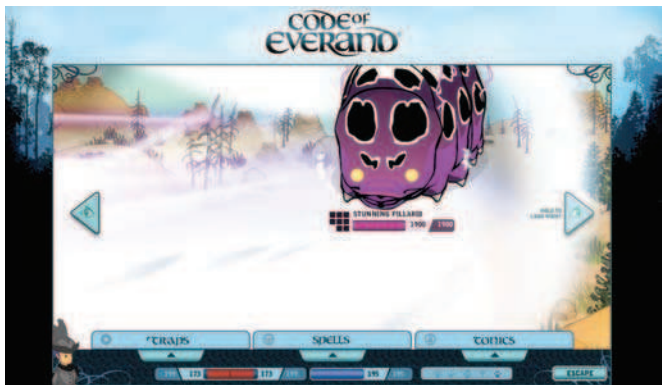
Columbia University

USING cheap components and few moving parts, Samuel Sia, an assistant professor at Columbia University, has helped create a microfluidic chip that tests blood samples for multiple diseases and is practical for use in poor countries. The chips cost pennies instead of dollars to make, and the results are read with a small battery-powered device.

Inventing the technology was just one step: Sia has given equal emphasis to getting it used. He and his partners wanted to develop microfluidics for use in poor countries, but they realized they would have trouble finding funding for such a venture. So in 2004 they founded a company, Claros Diagnostics, to create a prostate-cancer monitor for use in the United States and Europe. They received $7.8 million in venture funding in 2007, and marketing approval was granted in Europe in June of this year *(see To Market, p. 21)*. While Sia's partners worked full time on that device, Sia modified the technology to create a test for sexually transmitted diseases, including HIV, syphilis, and hepatitis.

Intending the test for use in Africa, he then orchestrated a number of field trials in collaboration with Columbia's school of public health and the Rwandan government. His efforts have progressed further than many other attempts to deploy new medical technologies in the developing world, but he still faces the hurdle of finding funding to commercialize the chip. "There are mechanisms to get money to develop new technology," he says. "But getting funding to implement it [on a broad scale] is very difficult."—*Emily Singer*

JOSHUA SCOTT



FAIL-SAFE
Schoolchildren playing this game must face monsters when crossing roads; the unpredictable behavior of the monsters is derived from real traffic data.

INTERNET

Kati London, 34

Teaching real-world skills through games

Area/Code

Kati London is blending the virtual and physical worlds to entertain—and to shape the real-life behavior of players. London, a vice president and senior producer at New York–based game company Area/Code, makes games that incorporate real-world data ranging from the mundane (the locations of players) to the exotic (signals from tracking devices attached to sharks in the Pacific). Many of her games are just for fun, but others are more serious.

For example, the U.K.'s Department for Transport commissioned Area/Code to make an online game for children aged 9 to 13, the group most at risk of being killed or seriously injured while crossing the street. When users reach a road in the fantasy-themed game, they can cross at designated safe spots and must look both ways for monsters. The monsters' behavior reflects that of vehicles; at some crossings, their speed and number is based directly on traffic data from actual intersections in the U.K. By replicating the unpredictable variations in the appearance, speed, and number of vehicles, London believes, the game teaches skills that children need to handle real traffic. More than 160,000 players have been registered since the game was introduced last year, and an independent evaluation is due out next spring. *—Kristina Grifantini*

MATERIALS

Michelle Povinelli, 34

Predicting better photonic devices

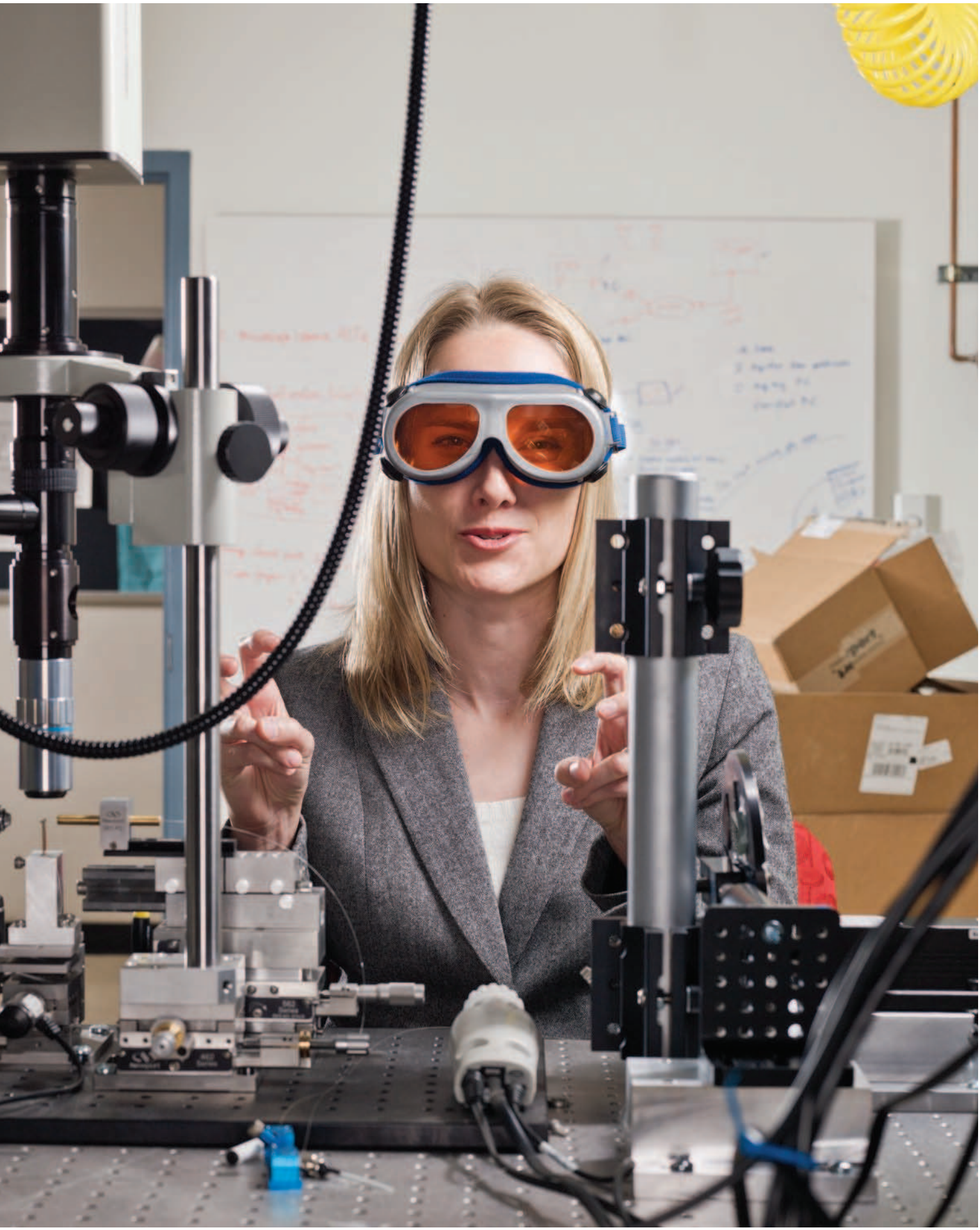
University of Southern California

UNDERSTANDING precisely how light behaves as it moves through devices such as solar cells or optical chips will lead to more efficient devices—and reveal new physical phenomena that engineers can exploit. To this end, theoretical physicist Michelle Povinelli is creating models of how photons interact with complex materials.

In one surprising finding, Povinelli correctly predicted that light being guided down a strip of silicon would exert a mechanical force on an adjacent strip. If moving parts driven by light were incorporated into optical circuits and used to reroute light signals, the light might not have to be converted into electricity for processing and then back to light again.

Making better solar cells may sound very different from optical communications, but understanding how light interacts with a device is equally important in this context. Povinelli is working on models to predict the efficiency of solar cells that have different nanostructures. Finding the ultimate efficiency for these cells will set a boundary on what researchers can hope to achieve and guide them toward photovoltaics that are less expensive but much better at generating electricity. *—Katherine Bourzac*

MISHA GRAVENOR



SOFTWARE

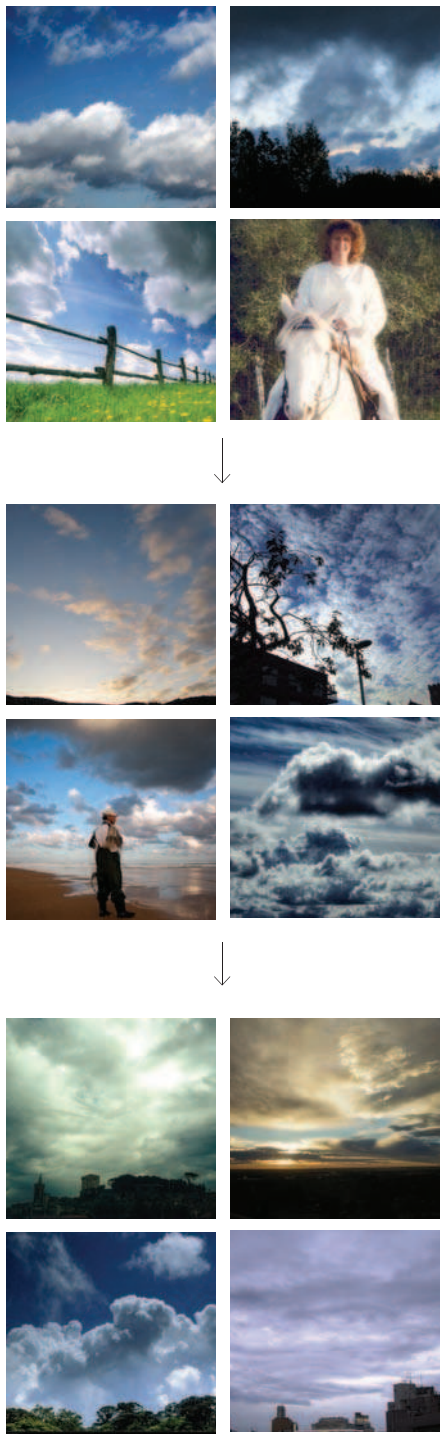
Jian Sun, 33

Better image searches

Microsoft Research Asia

PROBLEM: Images are hard for search engines to index because computers find it difficult to identify their content. Algorithms called classifiers can sort images using statistical techniques, but that presents something of a chicken-and-egg problem: ideally, "you need millions of [classified] images to train a classifier," says Jian Sun, a researcher at Microsoft Research Asia in Beijing.

SOLUTION: Sun developed a way to make it easy for humans to train computers in picture classification. With his system, which was recently incorporated into Microsoft's Bing Images search engine, users enter a search term—say, "cloudy sky." Using its existing classification algorithm, Bing makes its best attempt to present a grid of images that match the search term. The user can click on a nearly right image and ask to see similar pictures, repeating the process until the perfect image appears. As the user refines the search, each click is fed back into the classifier. This means the next time a user searches for "cloudy sky," Bing will immediately present a more relevant set of images than before. The system is also being used to help other researchers develop image search algorithms; incorporating results from Bing, Sun has released a training database containing 100,000 categorized images. *—David Cohen*



LEARNING MACHINE Bing lets users refine search results (top), producing images that better match a search term (middle). New searches will then produce better initial results (bottom).

BIOTECHNOLOGY

Timothy Lu, 29

Engineering viruses to destroy biofilms

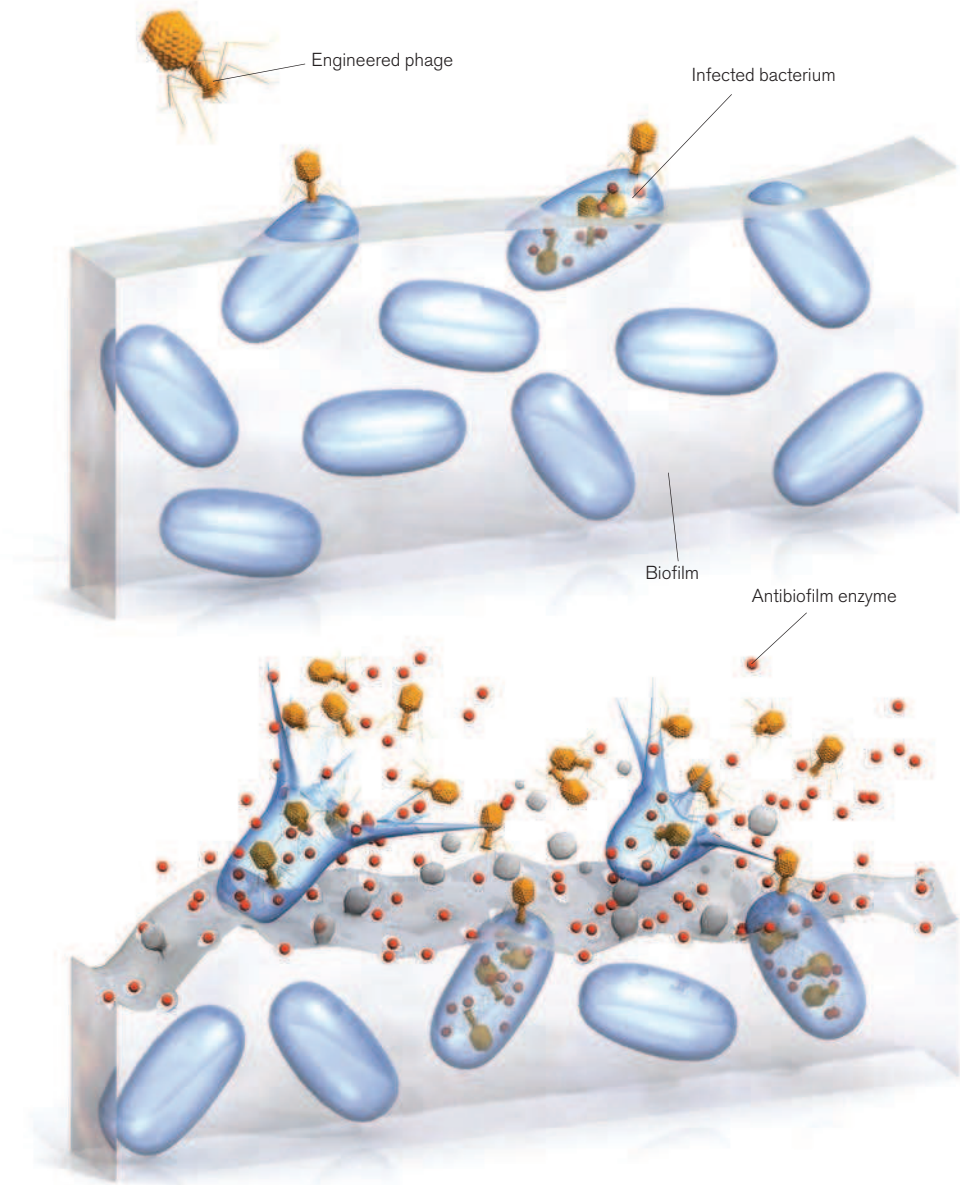
Ascendia Biotechnology, MIT

At Harvard Medical School, many of Timothy Lu's patients were being attacked by carpets of microbial goo. They had "really bad infections," Lu says. "Patients with cystic fibrosis, people getting infections in their catheters. All caused by biofilms."

Lu, who is now an assistant professor at MIT, began researching how to destroy biofilms. But unlike those who had previously attacked the problem, he took advantage of the new tools of synthetic biology. He engineered a type of virus, known as a phage, to destroy biofilms and sabotage their defenses against antibiotics. His accomplishment could produce synthetic biology's first big commercial success by attacking the biofilms that infest industrial equipment.

When bacteria settle on a surface, they spew out molecules that bind the entire population together and cover it in a protective shield. Bacteria in these biofilms are up to 500 times more resistant to antibiotics than free-floating microbes are. Normally, viruses have a hard time penetrating the dense layers of a biofilm. But Lu stumbled across an enzyme produced by oral bacteria that can break up biofilms. He inserted the gene for the enzyme into a phage called T7 so that when the virus infects a microbe, it makes as much of the enzyme as possible.

When the engineered T7 is unleashed on a biofilm, it invades the top layer of bacteria. These bacteria soon burst open, spilling out enzymes and new phages. Aided by the enzyme, the viruses then penetrate the next layer of bacteria, repeating the cycle until the biofilm is destroyed. Lu and his colleagues have also found other ways to



THE BANE OF BIOFILMS Bacteria bound together in a protective matrix tend to resist viral attack. But Lu's virus produces an enzyme that breaks up these biofilms. When it infects the bacteria on the biofilm's surface, they burst and release viruses that infect those underneath, soon exposing even deeply embedded bacteria to infection.

BRYAN CHRISTIE DESIGN

turn phages into effective weapons against biofilms, such as creating versions that can shut down the genes that bacteria use to defend themselves against antibiotics.

Last year Lu cofounded Novophage (now called Ascendia Biotechnology) to develop commercial applications for the phages. The company is initially concentrating on biofilms that Lu says can corrode water pipes and block heat transfer in heating and cooling systems, decreasing energy efficiency by up to 80 percent. Conventional industrial attempts to deal with biofilms have involved scrubbing pipes, applying chemicals, or exposing the films to ultraviolet light, but these treatments are not very effective, can damage piping, and are toxic to humans and the environment. A small injection of phages into a water pipe, however, could clean an entire system, with the phages replicating themselves as they consume the biofilm. *—Carl Zimmer*

INTERNET

Christopher Kruegel, 34

Developing software that shuts down botnets

University of California, Santa Barbara

BOTNETS—armies of enslaved computers that have been infected with carefully crafted worms or viruses—are responsible for more than 80 percent of the over 100 billion spam messages e-mailed daily. Antivirus programs are often ineffective against them, because the software typically works by scanning a computer for signatures of known viruses—and the viruses that turn computers into bots are often too new for these characteristic patterns to have been identified. Christopher Kruegel, a security researcher in the computer science department at the University of California, Santa Barbara, has developed technology that can ferret out an infection even if the virus or worm has no known signature. In 2009, he cofounded a startup called LastLine to commercialize the technology.

It works by detecting when a botnet virus is communicating with its master servers, as it must do to get its commands or to send back data—say, your passwords and credit card numbers. To identify these communications amid legitimate network traffic, Kruegel's research group analyzed tens of thousands of malware samples per day and teased out the command-and-control messages common to botnets.

Catching these communications makes it possible to block the master servers, forcing criminals to move their infrastructure or redirect their communications. In effect, Kruegel isolates the previously infected computers, neutralizing the infection even if it hasn't been wiped from your hard drive.

—David Talbot

SOFTWARE

Rikin Gandhi, 29

Educating farmers through locally produced video

Digital Green

About 600 million people in India depend directly on agriculture for their livelihood. One of the ways the country's ministry of agriculture tries to help them is by broadcasting videos about farming techniques. In one, for example, officials describe how to plant a fern called azolla in otherwise unusable wet spots; it can be used to make extra cattle feed that enables cows to give more milk. But partly because of cultural and ethnic differences between the ministry workers and the villagers, the government advice is widely ignored.

Rikin Gandhi, founder of the nonprofit Digital Green, has developed a pilot project that offers a solution: simple videos starring local farmers themselves. Gandhi demonstrated that for every dollar spent, the system persuaded seven times as many farmers to adopt new ideas as an existing program of training and visits.

Gandhi—who helped launch the program as a 2006 project at Microsoft Research, India—spent six months testing various video schemes in villages in the state of Karnataka before concluding that featuring local farmers was the key. Villagers produce the videos using handheld camcorders; workers from partner nongovernmental organizations then check the quality of the videos and the accuracy of the advice before screening them in the villages with handheld projectors. So far 500 videos have been made, but three times that number—which should reach four times as many villages—are currently planned. *—David Talbot*

ENERGY

Lyndon Rive, 33

Leasing solar power

SolarCity

WHAT WILL it take to get you to install solar panels on your roof? Lyndon Rive, solar's master salesman, wants to know. Thanks to an innovative leasing program, among other sales enticements, SolarCity has become the largest residential solar installer in the United States. The company, which is based in Foster City, CA, has installed more than 8,000 solar systems since 2006. It tripled in size this year, and Rive, its CEO and cofounder, expects it to double next year.

To reduce the high up-front costs for customers, Rive will lease homeowners the panels at a rate based on the size of their system. As the panels produce power, surplus electricity is sold to the local utility, and Rive says that those sales, combined with the savings from using less power from the grid, will typically reduce the homeowner's electric bill by more than enough to offset the lease payments. He has hired a team to create software that can manage hundreds of thousands of solar projects in 1,000 jurisdictions, each with its own particular requirements. By saving "pennies here and pennies there," he says, and increasing the volume of installations, Rive is driving down the costs of solar power. His hope is that solar will be able to survive without government subsidies in six to eight years. *—Kevin Bullis*

DIGITAL GREEN

SITTING PRETTY
Lyndon Rive's company, SolarCity, designs and manufactures the solar power systems it installs.

JON SISKA

35

TELECOMMUNICATIONS

Gabriel Charlet, 34

Record-breaking optical fibers for global communications

Alcatel-Lucent

BAUDOUIN

The 2,000 kilometers of fiber-optic cable stacked in Gabriel Charlet's lab in the Alcatel-Lucent Bell research facility in Nozay, France, are a reminder of a record-breaking achievement: in 2009 Charlet smashed the world high-speed long-distance record for fiber-optic communications, reaching a transmission rate of 7.2 terabits per second over a single fiber 7,040 kilometers long. That's around five times as fast as existing commercial systems—the equivalent of transmitting more than 6,000 movie-length DVDs in a minute.

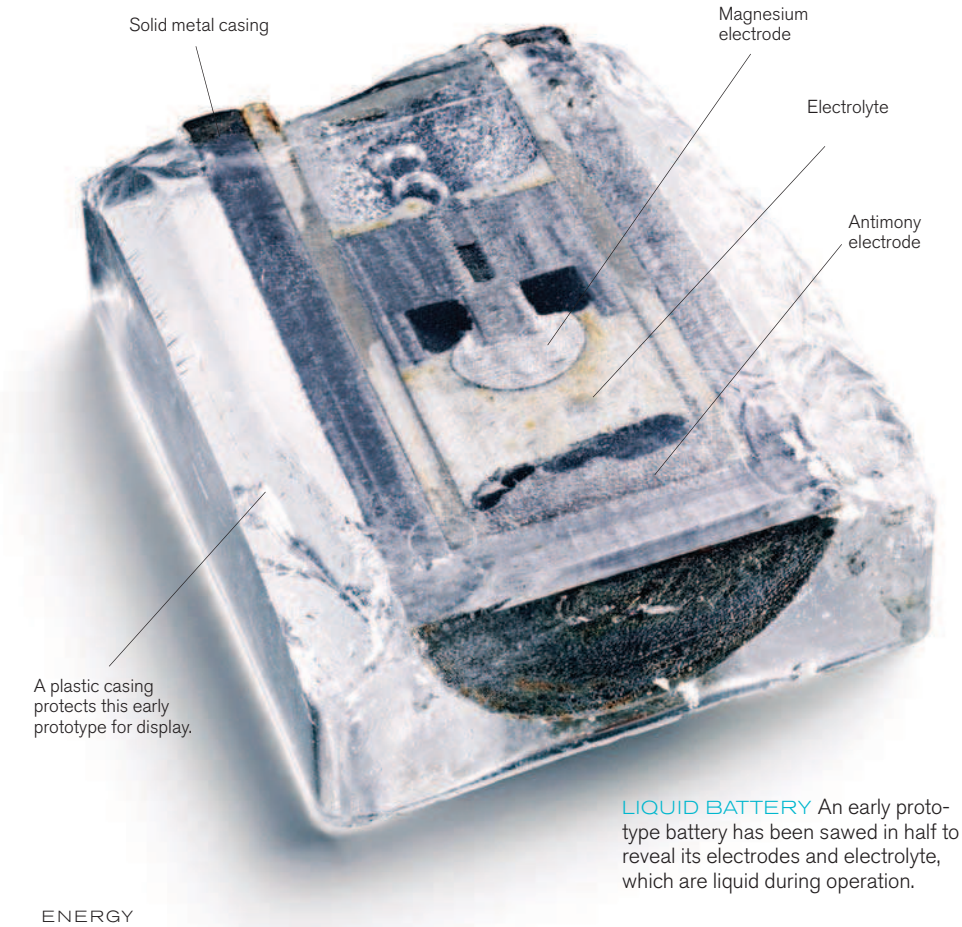
Charlet reinvigorated a field. The data-carrying capacity of the cables that form the backbone of the global telecommunications network had improved little in recent years: as other researchers tried to boost transmission rates, microscopic imperfections in the cables introduced distortions that could not be compensated for. These researchers were encoding digital data by varying the intensity of a pulse of light. For example, high intensity would represent a 1 and low intensity would represent a 0. At high data rates over long distances, the imperfections blurred the distinction between intensity levels, meaning that at distances over 7,000 kilometers, around 1.2 terabits per second was the limit of reliable communication.

To solve the problem, Charlet perfected a system that uses the polarization and phase of a pulse of light, rather than its intensity, to encode data. Errors induced by imperfections are far less problematic thanks to the development of a new receiver that detects the whole electrical field of the signal, rather than just its intensity. As a bonus, each pulse of light can now encode four bits of data instead of just one, because different polarizations can be used to indicate different bit values.

Drawing on Charlet's research, Alcatel-Lucent recently launched a new generation of commercial equipment that transmits data at 3.2 terabits per second over distances of up to 7,000 kilometers (the speeds are slower than Charlet's record because of the limitations of current chip designs; the next generation will use specially made chips). The next time you watch a video on YouTube, it may have been piped to you with Charlet's help. *—David Cohen*

SPEEDSTER Spools containing thousands of kilometers of fiber-optic cable let Gabriel Charlet push the boundaries of high-speed long-distance data transmission.

JOSHUA SCOTT



LIQUID BATTERY An early prototype battery has been sawed in half to reveal its electrodes and electrolyte, which are liquid during operation.

ENERGY

David Bradwell, 28

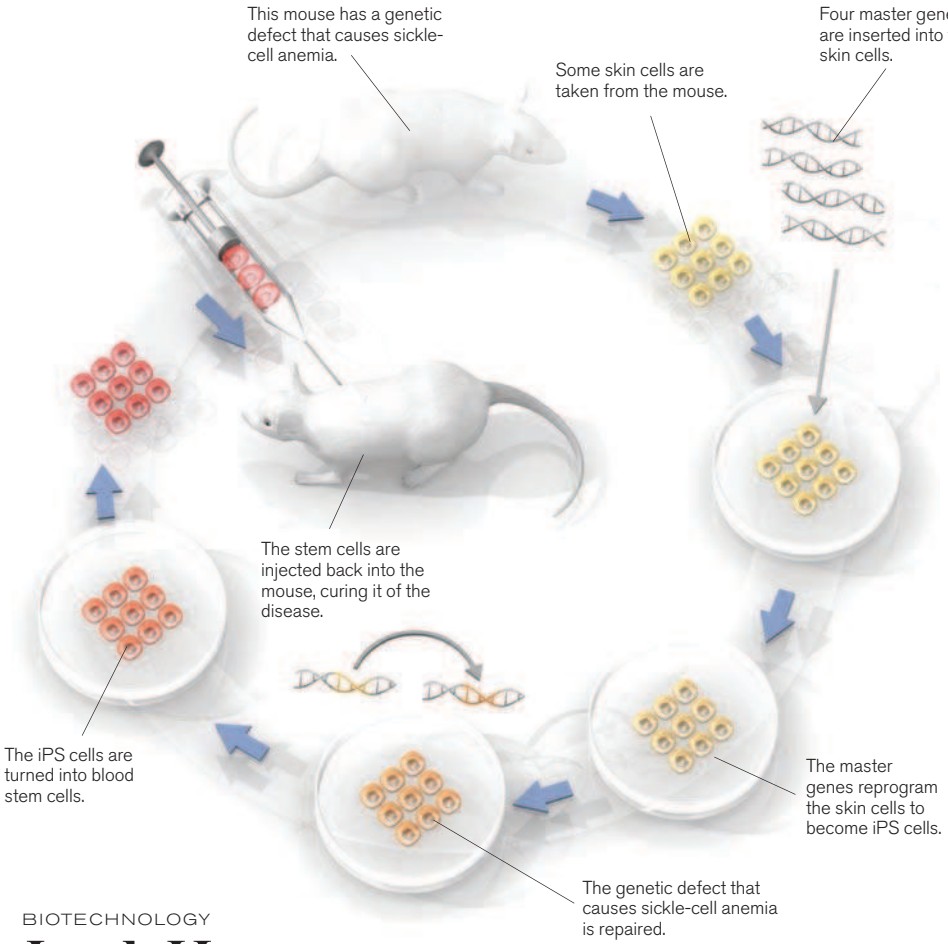
Cheap, reliable batteries to store renewable energy

MIT

In the fall of 2007, David Bradwell, an MIT grad student, created a new kind of battery—one that might eventually be used to store massive amounts of solar and wind energy for use at night or when the wind isn't blowing. Unlike existing batteries, it has active components that are liquid, which enables it to handle high currents without fracturing (the battery is kept at 700 °C with the help of insulation). Last year Bradwell's research attracted a total of about $11 million from the U.S. Department of Energy's new Advanced Research Projects Agency–Energy (ARPA-E) and the French oil company Total.

Bradwell's battery is based on an electrolyte that can dissolve a compound consisting of two metals, such as magnesium and antimony. Applying a current in one direction splits the compound, and the two metals are deposited onto opposite electrodes. When no electricity is delivered, a voltage difference between the electrodes drives a current in the other direction. That generates electricity and causes the metals to recombine in the electrolyte.

The system could eventually cost less than $100 per kilowatt-hour for a new installation—about the same as pumping water up a hill to be released later to spin a turbine (the cheapest conventional approach for large-scale energy storage), says Arun Majumdar, the director of ARPA-E. The battery, however, would have the advantage of working in places without hills or large amounts of water, where many renewable power resources are located. *—Kevin Bullis*



BIOTECHNOLOGY

Jacob Hanna, 30

Reprogramming cells to cure diseases

Whitehead Institute

Mere months after Kyoto University researchers announced in 2007 that they had discovered how to turn skin cells into induced pluripotent stem cells (iPS cells), Jacob Hanna used these new types of cells to cure mice of sickle-cell anemia, in which a genetic defect causes bone marrow to make defective red blood cells. Hanna, a fellow at the Whitehead Institute, took skin cells from a diseased mouse and reprogrammed them to create iPS cells, which behave like embryonic stem cells, readily turning into any cell type in the body. He then corrected the genetic defect and prodded the iPS cells to develop into the type of marrow stem cell that manufactures a mouse's blood cells. These healthy cells were transplanted back into the mouse, whose immune system accepted them as the animal's own tissue. The treated mouse began producing healthy red blood cells on its own.

Hanna's work was a turning point for iPS research, says George Daley, director of the Stem Cell Transplantation Program at Boston's Children's Hospital and a professor at Harvard Medical School: "It was a beautiful demonstration of a mouse model of a human disease, and really demonstrated the potential of iPS cells."

Before iPS cells can be used to treat diseases such as sickle-cell anemia in humans, a lot of work has to be done to make sure they won't cause adverse side effects and to improve the efficiency of deriving them from skin cells. Hanna is now developing simulations to understand what happens when cells are reprogrammed, and he's searching for new types of human stem cells that could be easier to turn into adult cells. —*Nidhi Subbaraman*

SOFTWARE

Kim Hazelwood, 34

Reëngineering software on the fly

University of Virginia

IMAGINE having a team of mechanics pull apart and retune your car's engine as you hurtle down the highway, without making the engine miss a stroke. That's the nature of the challenge that motivates Kim Hazelwood, an assistant professor of computer science, who has created tools to rewrite software as a computer is executing it. Before she started working on the problem in grad school, "I would have said there's no way you can just take programs and change them and have every program work," says Hazelwood. But industry giants like Intel and researchers around the world have used her subsequent achievements to do just that.

Hazelwood's approach contradicts one of the most important notions in computer programming—abstraction. Abstraction means that software is built in layers: an application runs on top of an operating system, which runs on top of the hardware. Each layer does its best to conceal its inner workings. That way, someone writing, say, a Web browser doesn't have to know all the engineering that went into a processor. At times, however, it would be useful for the application and hardware layers to communicate more directly. For example, some modern processors reduce electricity consumption by turning off portions of the chip until they are

BRYAN CHRISTIE DESIGN

THE REPROGRAMMER Kim Hazelwood's technology allows computers to adjust software so it works better with the hardware it's running on.

ELI MEIR KAPLAN

needed, but an application that causes this to happen excessively can shorten the life of the chip. Hazelwood's software can monitor the processor and detect when subsystems are being turned off and on too often. It then analyzes the software instructions that are triggering the problem and substitutes more hardware-friendly commands that do the same job.

The ability to monitor and modify applications while they're running could be widely useful. For example, it could make it easier to compensate for hardware bugs, divide tasks among multiple processors, run software on different processor architectures, and even defend against malicious software.

—Stephen Cass

TRANSPORTATION

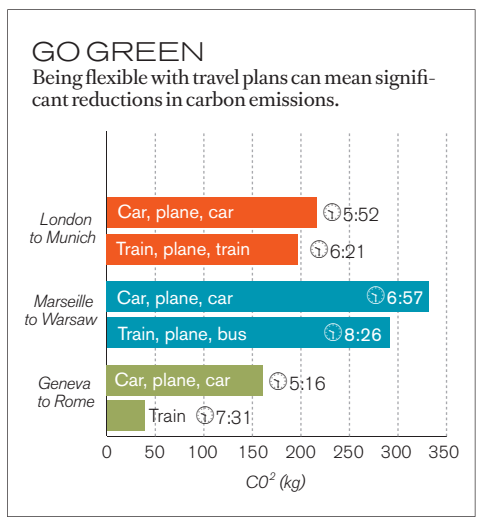
Jochen Mundinger, 32

Reducing the carbon footprint of travel

RouteRank

FRUSTRATED by trying to coördinate different modes of transport to get from Switzerland to a conference in Poland four years ago, Jochen Mundinger had an idea for a search engine that would find the fastest, cheapest, or most ecological way to get from A to B. Mathematically, what's involved is a network optimization problem under a particular set of constraints—a perfect fit for Mundinger, who was trained as a network analyst and works at the Swiss Federal Institute of Technology in Lausanne. In 2007, he turned the idea into a company, RouteRank.

Type in, say, "Basel" and "Munich" in RouteRank and the system will find not only flights but also trains, public transport, and driving routes—and let you combine them. A



click of your mouse lets you sort the results according to what you consider most important, whether that's price, travel time, or environmental considerations. RouteRank calculates the carbon dioxide emissions associated with each itinerary and lets you offset them by connecting you to Myclimate, a Swiss-based nonprofit foundation. Today RouteRank provides customized commercial service to Nokia, the conservation group WWF, and, most recently, the Swiss government. One surprising discovery, says Mundinger, is that the fastest way of getting somewhere isn't always the least green. Next steps include expanding beyond Europe.

—Giselle Weiss

SOFTWARE

Andrey Rybalchenko, 32

Stopping software from getting stuck in loops

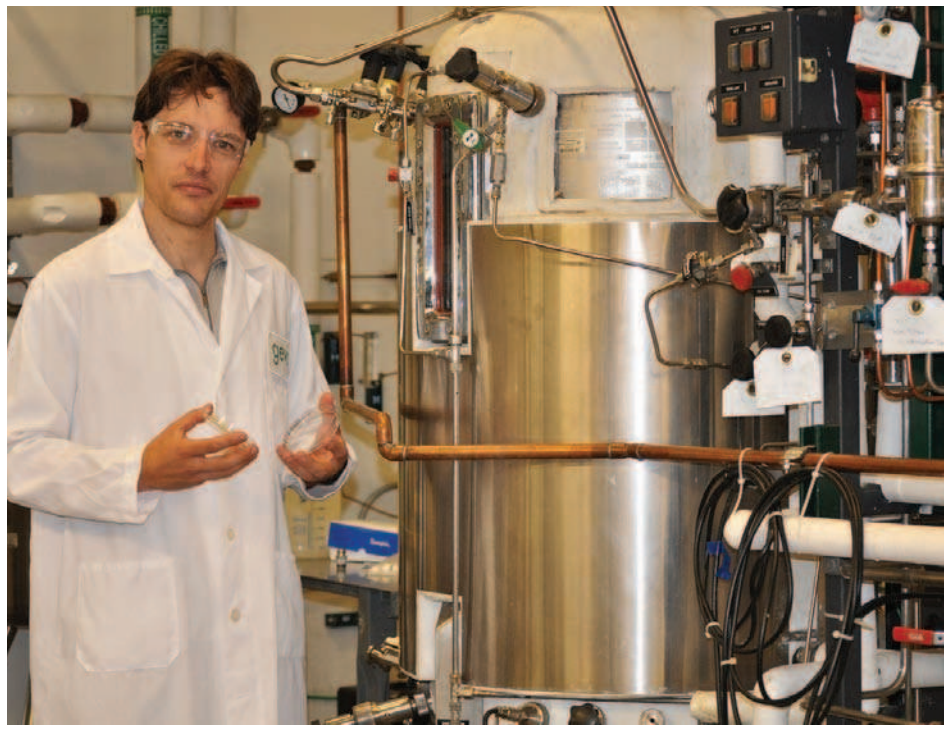
University of Technology, Munich

COMPUTER scientist Andrey Rybalchenko has developed a new method for finding software bugs. Traditional automated testing systems detect when programs do "bad things" that lead to crashes, forcing the program to quit. By focusing on crashes, however, such testing often misses a significant class of bugs—those that allow the software to keep running but leave it unable to accept new input or do anything useful. In essence, Rybalchenko instead tries to identify when a program is doing "good things," such as making progress through loops or responding to other programs.

In a collaboration with Microsoft that began in 2006, Rybalchenko incorporated his methods into Terminator, a commercial program used to find bugs in the device drivers that mediate between an operating system and various pieces of hardware. Countless device drivers have been created by third-party developers, and they are often responsible for software failures that users blame on the OS. So detecting these bugs improves both actual and perceived OS reliability.

Rybalchenko is currently seeking ways to detect similar bugs that can appear when many processors work simultaneously on the same task but fail to coördinate properly and begin competing instead. Now that processor speed has plateaued at a little over three gigahertz, this kind of problem will become more and more significant as manufacturers turn to multicore systems to continue improving performance.

—Giselle Weiss



COURTESY OF GEVO

ENERGY

Peter Meinhold, 34

Engineering a better bug for biofuels

Gevo

As a biofuel, ethanol is relatively easy to make, but it has a lower energy density than gasoline and can't be transported through existing pipelines designed for petroleum fuels. Isobutanol, however, can be sent through these pipelines, and its energy density is close to that of gasoline. It can also be turned into jet fuel, and it can be used as a raw material for the manufacture of plastics and many other chemicals normally derived from petroleum.

Both ethanol and isobutanol are made from sugars produced by breaking down biomass. But it's not easy to produce isobutanol with the help of microbes like the ones that ferment those sugars into ethanol. So Peter Meinhold rewired the yeast genome, replacing genes that controlled ethanol fermentation with genes for a enzymatic pathway that would produce isobutanol. He cofounded Gevo in 2005 to commercialize the technology and produce isobutanol that would be cost-competitive with petroleum-based fuels.

Gevo has also enhanced the isobutanol-producing capacity of its yeast by developing a system that continously removes isobutanol as it is produced. (Otherwise, high concentrations of isobutanol would inhibit the growth of the yeast.) The company is also developing new versions of the yeast that can feed on sugars produced from grasses and wood chips. In 2009, Gevo announced the startup of a million-gallon-per-year demonstration facility retrofitted into an ethanol plant. The company has set a goal of going to market by 2012. *—Nidhi Subbaraman*

BIOTECHNOLOGY

Philip Low, 31

Liberating patients from sleep clinics

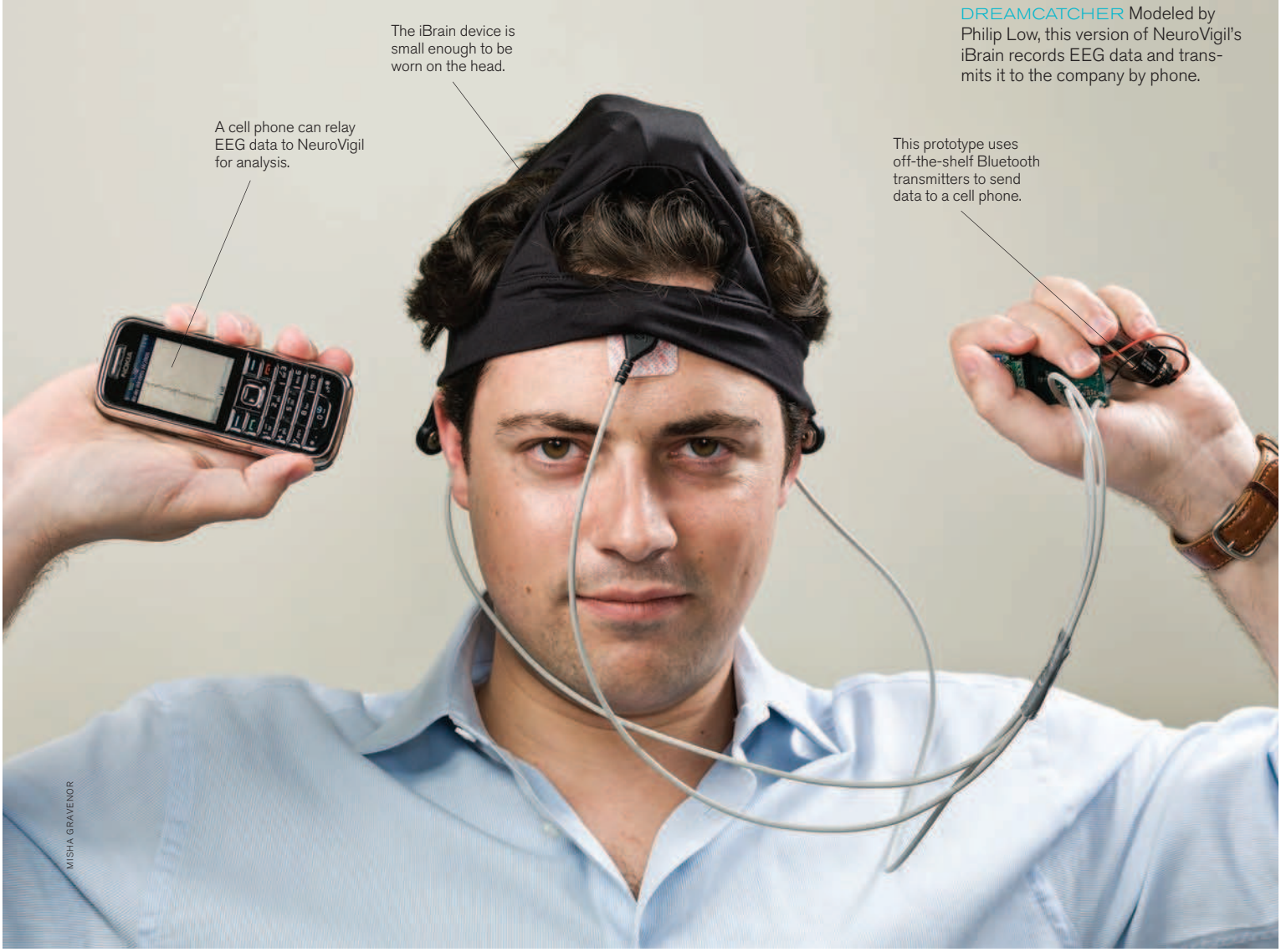
NeuroVigil

The study of sleep has been a cumbersome affair. Test subjects must spend the night on a laboratory bed, hooked to machines by over a dozen leads. The next day, a technician scores the machines' output by hand, categorizing each 30-second interval by stage of the sleep cycle.

Philip Low, seeking a better way, created an algorithm that can classify sleep stages using data from just a single LED lead. In 2007 he founded NeuroVigil, a startup based in La Jolla, CA, that manufactures a sleep-monitoring device based on the technology.

The device is small enough to be worn on a headband, so subjects can sleep at home rather than at a clinic. To make life even easier for subjects, the company is developing a version of the device that gathers data and beams it to a subject's cell phone, which can then send it wirelessly to NeuroVigil for analysis.

Pharmaceutical companies use the device to watch for brain-related side effects when testing therapies for disorders of the central nervous system. NeuroVigil has used these trials to amass a database of readings from patients with particular diseases. Low hopes that by mining this database, he will discover EEG signatures in the data that might warn of conditions like Alzheimer's, schizophrenia, or Parkinson's before symptoms appear. —*Jocelyn Rice*



DREAMCATCHER Modeled by Philip Low, this version of NeuroVigil's iBrain records EEG data and transmits it to the company by phone.

MISHA GRAVENOR

TELECOMMUNICATIONS

Ranveer Chandra, 34

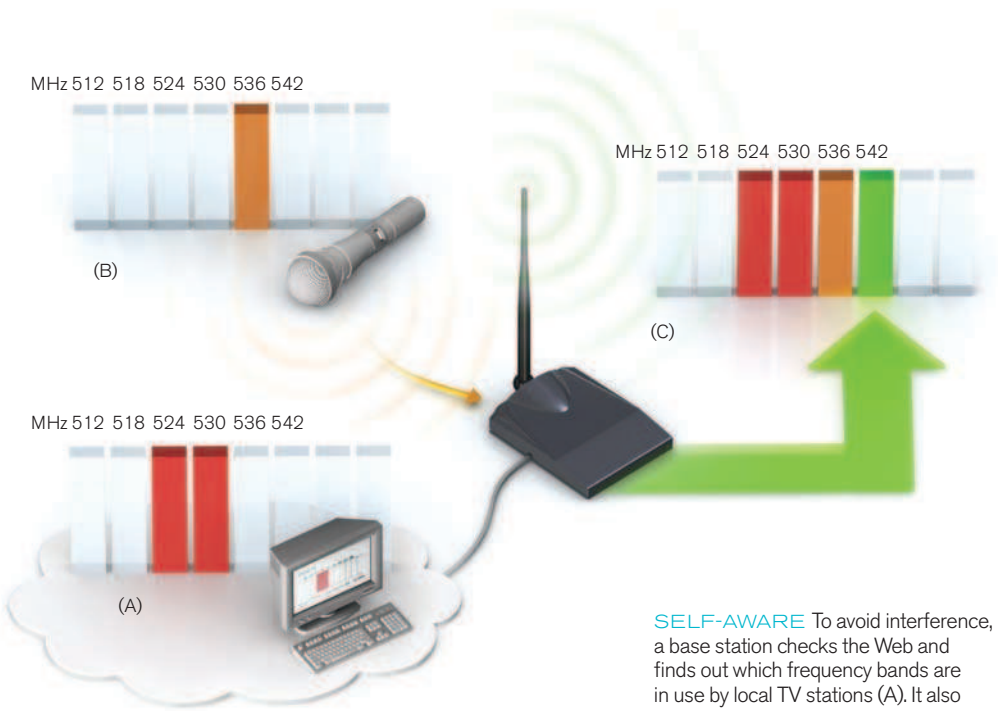
Delivering high-speed wireless Internet connections over longer distances

Microsoft Research

PROBLEM: Wi-Fi uses frequencies that can't carry a signal more than a few tens of meters. TV stations, on the other hand, use a portion of the radio spectrum that lets signals travel long distances, and the end of analog television has opened up unused slices of the spectrum between stations. They could be used for wireless Internet service, but it has been difficult to take advantage of these so-called white spaces without causing interference, because the exact frequencies used by TV stations vary geographically.

SOLUTION: Ranveer Chandra made the Microsoft campus in Redmond, WA, his laboratory for the first large-scale network to demonstrate the potential of using white spaces to deliver broadband wireless. Links in the prototype network can span up to two kilometers. To avoid treading on the toes of TV broadcasters, his system uses GPS to determine its location; then it checks the Web to find out what stations are active in the area. Chandra's devices can also listen for nearby transmissions from wireless microphones, which use the same bands. When a conflict is detected, they switch to a backup slice of unused spectrum on the fly.

If such a system gains currency, "all of us should be connected and better connected, and not just here in the U.S.," says Chandra. Spectrum regulators from Singapore, India, Brazil, and China have all come to visit his prototype network to explore the potential for white-space signals to connect large rural areas with minimal infrastructure. *–Tom Simonite*



SELF-AWARE To avoid interference, a base station checks the Web and finds out which frequency bands are in use by local TV stations (A). It also listens for any wireless microphones in range (B) and picks a free band (C).

MATERIALS

Alán Aspuru-Guzik, 34

Simulating chemistry with quantum computers

Harvard

IN THEORY, quantum mechanics should offer perfect understanding of some of the most interesting events in chemistry—for example, the behavior of excited electrons, which controls such things as photosynthesis in plants. In practice, however, the necessary calculations are far too difficult for even the most powerful computers. So approximations must be made, especially when larger molecules such as proteins are involved.

Alán Aspuru-Guzik, a theoretical chemist at Harvard, is developing methods that could one day do away with the need for approximations altogether—and lead to better drugs or solar cells.

He has created an algorithm that allows quantum computers to simulate chemistry with a level of accuracy that traditional computers will never be able to match. Although quantum computers are not yet powerful enough to simulate the behavior of large molecules, Aspuru-Guzik and collaborators in Australia, working with an experimental quantum computer, successfully used the algorithm to compute the energy of the hydrogen molecule.

Aspuru-Guzik is also probing the quantum effects at the heart of photosynthesis in the hopes of developing cheaper and more efficient organic photovoltaics.

–Neil Savage

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35

MATERIALS

Conor Madigan, 32

Bringing down the price of OLED displays

Kateeva

Television displays based on organic light-emitting diodes are brighter, crisper, and more energy efficient than liquid-crystal displays. But they're very expensive, especially for large-screen models. Conor Madigan is working to drive down the cost of these displays as the CEO and cofounder of a Silicon Valley startup called Kateeva, which is developing efficient machinery for printing pixels over large areas. The technology makes it possible to manufacture OLED screens at 60 percent of the cost of LCD screens.

Kateeva is sending out a beta version of its OLED-display printers to customers for evaluation in the first half of 2011 and hopes to have its first production tools on the market in 2012. If OLEDs replace LCDs, Kateeva could tap into a $10-billion-a-year market for display-manufacturing equipment.

—Katherine Bourzac

SOFTWARE

Indrani Medhi, 32

Building interfaces for the illiterate

Microsoft Research India

INFORMATION is at the fingertips of anyone with access to a laptop or smart phone. But what if the user is one of the 774 million adults worldwide who cannot read? This is the problem that obsesses Indrani Medhi. Based at Microsoft Research India's Bangalore lab, she has conducted field research in India, South Africa, and the Philippines to design text-free interfaces that could help illiterate and semiliterate people find jobs, get medical information, and use cell-phone-based banking services.

WORDLESS Medhi's interfaces guide illiterate and semiliterate users through tasks such as electronic banking.

Meaningful computer icons are rarely the same from one culture to another, Medhi says, so she used symbols, audio cues, and cartoons that are specific to particular poor communities. But then she encountered another hurdle. Even when users became familiar with the hardware and the interfaces, Medhi realized, they still did not fully understand how information relevant to their lives could possibly be contained in or delivered by a computer.

The key to overcoming this problem, she discovered, is to offer a five-minute video dramatization when an application is launched, illustrating exactly how it is supposed to work. For example, the one that accompanies her job-search interface features an upper-middle-class couple that needs a domestic helper. The husband posts the requirements to a job website that is subsequently accessed by unemployed and illiterate women at a community center. The video ends with a woman being hired. *—Guy Gugliotta*

JEN SISKA (MADIGAN); INDRANI MEDHI/MICROSOFT RESEARCH INDIA

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By EMILY SINGER

A Family Mystery, Solved by a Genome

Physicians can now use DNA sequencing to uncover the causes of rare genetic disorders.

More than a dozen people who have had their genomes sequenced stand on stage in an R&D center near Boston. Billed as the last time all such people might fit in one room before the technology moves into the mainstream, the event doesn't quite include the whole group: actress Glenn Close and South African archbishop Desmond Tutu, among others, didn't make it. But those who did include James Watson, codiscoverer of the structure of DNA; Harvard historian Henry Louis Gates Jr.; entrepreneur Esther Dyson; and a smattering of leaders from gene-sequencing companies.

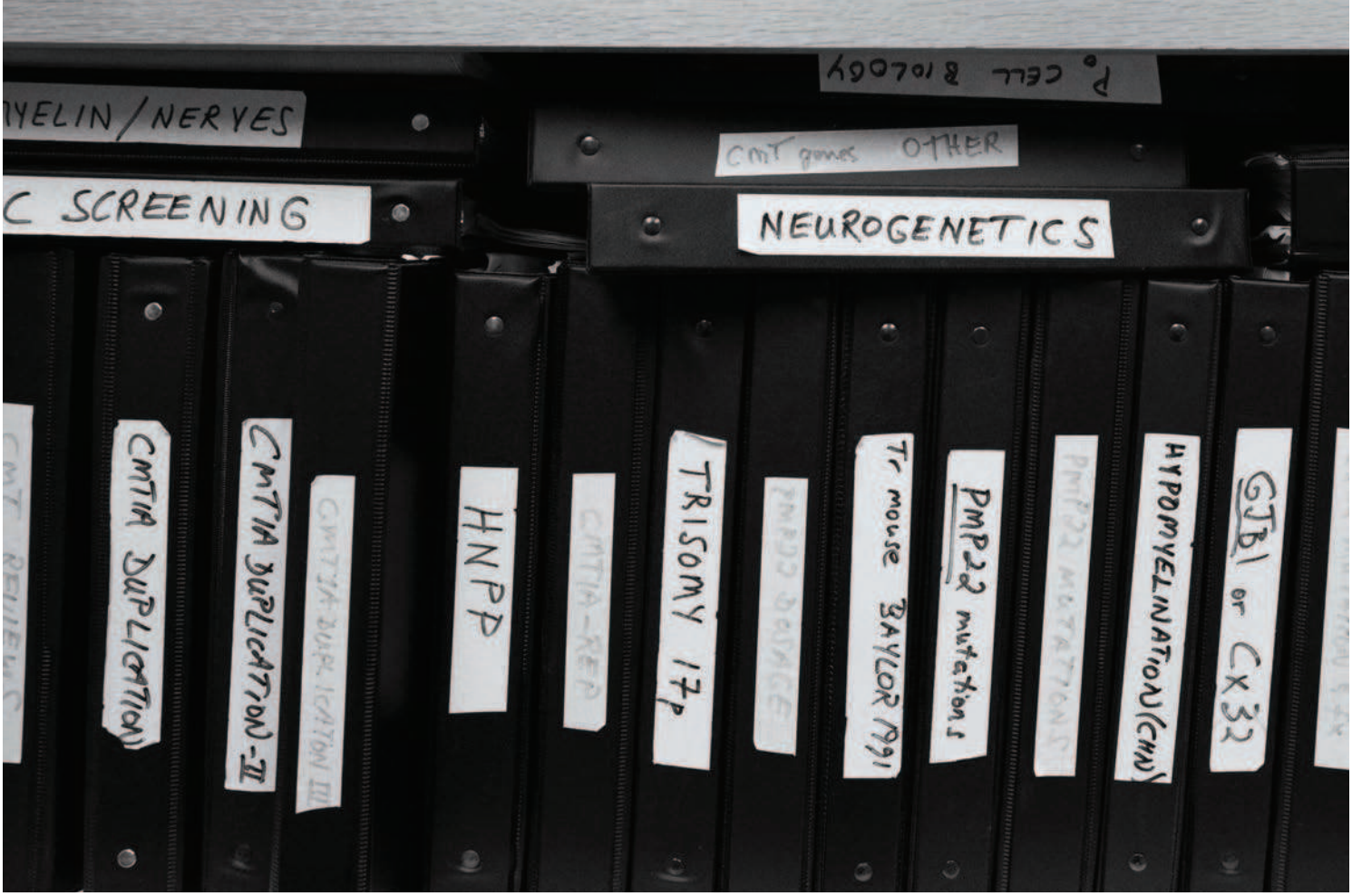
Leaning against a wall at one end of the stage is James Lupski, a pediatrician, clinical geneticist, and scientist at Baylor College of Medicine. Unlike many of the others, Lupski wasn't interested in sequencing as a way to trace his ancestry or determine his future likelihood of developing some ailment. Instead, he had hoped to solve a medical mystery that affects him in the most personal way: the cause of a genetic disorder, called Charcot-Marie-Tooth disease, that struck him and several of his siblings as teenagers, severely weakening the muscles in their legs and feet. After a quarter-century searching for the gene responsible, the 53-year-old scientist finally found it by scouring his own genome, combing through the billions of DNA building blocks represented by the letters A, T, C, and G. It marks the very first time that whole-genome sequencing—determining the exact order of all the letters in an individual's DNA—has identified the mutation to blame for a specific case of a genetic disease.

Since the human genome was first sequenced a decade ago, scientists have discovered thousands of genetic variations linked to different diseases. Until very recently, however, sequencing an individual genome cost millions of dollars, making it an impractical way to search for the cause of a particular person's genetic disorder. Now the cost of sequencing has fallen so dramatically that it's becoming realistic to do just that. A genetic test for inherited nerve diseases, which costs about $15,000, screens for only a limited number of genes. But now sequencing is available to consumers for $20,000 and provides the entirety of a person's genetic information. Searching through it can reveal genes and pathways whose role in a disorder scientists may never have suspected. This could help illuminate the more than a thousand rare genetic disorders for which scientists have been unable to pinpoint a specific culprit. And it could contribute to a new way of thinking about the role heredity plays in many common ailments, such as diabetes and Alzheimer's.

In Lupski's view, the frontiers opened by whole-genome sequencing will be to traditional Mendelian genetics what Einstein's discoveries were to Newtonian mechanics. "Newton

Photographs by MATTHEW RAINWATERS

FAMILY TRAITS After sequencing his genome, James Lupski discovered the mutations that led him and three of his siblings to develop a neurological disorder.



A CATALOGUE OF GENETIC MISTAKES James Lupski has spent the last 25 years searching for the genetic basis of a number of inherited disorders. The bookshelves of his Baylor office are filled with data on different mutations.

wasn't wrong," he says. "We were just expanding our understanding to include relativity." Mendel wasn't wrong either: single genes and certain diseases do follow Mendelian patterns of inheritance. But, he says, "there are genetic modifiers and new mutations that 'Mendelism' perhaps did not anticipate." Just as Newtonian physics is a special case of Einsteinian relativity, Mendelian inheritance is one piece of a more complete picture that will be revealed in the genome.

To bring that picture into better focus, Lupski is now sequencing the genomes of several patients with rare neurological disorders of unknown cause. The results are unlikely to have much immediate impact on their care: there are no effective treatments for their diseases right now. But the technology could offer new insight into those diseases and guide the way to future therapies.

THE HUNT

At Baylor's campus in Houston, the Human Genome Sequencing Center spans three floors of the building next to Lupski's office. The center, one of three nationally funded labs in the United States, became a key player in the Human Genome Project in the late 1990s. In 2007, its director, Richard Gibbs, invited Lupski to help sequence the genome of James Watson. The high-profile project, completed later that year, was a technical accomplishment because it employed a new generation of cheap sequencing technologies. But it also highlighted the limitations of the approach: they'd identified mutations in genes whose function they knew little about. What's more, Watson had no diseases that the researchers could try to trace to a gene. So Gibbs offered to sequence Lupski's genome.

When Lupski was first diagnosed with Charcot-Marie-Tooth as an adolescent in New York in the 1960s, the tools of human genetics were still rudimentary, and no disease genes had yet been identified. Physicians relied on particular symptoms and patterns of family inheritance to diagnose genetic disorders. In Lupski's case, three of his seven siblings developed muscular symptoms similar to his own, suggesting that they were suffering from a recessive genetic disease. The affected siblings had apparently inherited two mutant copies of an unknown gene, one from their mother and one from their father.

In 1983, while studying for both a medical degree and a PhD at New York University, Lupski picked up a copy of the journal *Nature* in which geneticists reported for the first time that they had identified the approximate location of a gene responsible for a human disease, in this case the neurological disorder Huntington's disease. (It would take another decade to find the gene within the target region.) Lupski decided that he could follow the example of the Huntington's researchers, who had studied

large families in which the disease was prevalent, to search for the genetic cause of his own disorder. That decision, which he now laughs off as naïve, would trigger a decades-long quest.

The strategy that Lupski and other gene hunters used in the 1980s was to build large family trees of relatives afflicted with a disorder. The scientists would then screen family members' DNA for genetic markers—specific sequences, found at spots on the genome known to vary from person to person—present only in those with the disease. If all the affected family members carried a particular marker and none of the unaffected family members did, the researchers hypothesized that the disease-causing variation was somewhere near that marker. Scientists needed to study large families in order to rule out markers that were inherited in this pattern by chance; the more subjects in a sample, the easier it is to distinguish a relevant signal from genetic noise. Large families were especially important in studying diseases like Charcot-Marie-Tooth, which has such variable symptoms that individual cases can be misdiagnosed. Once they had identified a likely marker, scientists would laboriously sift through the DNA in that area of the genome, looking for candidate genes and mutations in them.

> As more people have their genomes sequenced, it's becoming clear that Mendelian genetics isn't so black and white. Genetic variations once thought to follow Mendelian rules may behave in more subtle and complicated ways.

Lupski's efforts paid off in 1991, when he and his coworkers discovered the first genetic variation linked to Charcot-Marie-Tooth. A gene on chromosome 17, at a spot involved in producing the fatty insulation that covers nerve fibers, turned out to be duplicated in some people with the disorder. It was the first time a disease had been linked to a variation in the structure of DNA, rather than to a change in a single letter or some other simple alteration in sequence. (These mutations, now known as copy-number variations, have since been implicated in a wide array of diseases, including schizophrenia and autism.)

Over the next 17 years, Lupski's lab would identify a number of other genetic variations tied to the disease. Yet Lupski never found any of the newly discovered mutations in his own DNA. Then in 2008 came Gibbs's offer—an opportunity to examine every gene simultaneously. After Lupski and his team sifted through the roughly 90 gigabases of raw data generated by sequencing his genome, they identified approximately three million spots where his DNA differed from the reference sequence created by the Human Genome Project. They homed in on those variations found only in genes previously linked to Charcot-Marie-Tooth or other nerve disorders.

Finally, they found two mutations in a gene called SH3TC2, one inherited from each parent. With that anomaly in sight, the researchers defrosted a set of DNA samples that Lupski had collected 25 years earlier and sequenced the gene in his siblings, his parents, and his late grandparents. He and all of his affected siblings turned out to carry both mutations, while the unaffected family members carried either one or none.

MENDEL REVISITED

The variant of Charcot-Marie-Tooth disease that Lupski suffers from is a Mendelian disorder, meaning that it is caused by mutations in a single gene. (Many other diseases—typically more common ones, such as diabetes and heart disease—are triggered by a combination of complex genetic and environmental factors.) Some Mendelian diseases, known as dominant disorders, affect people who inherit just one copy of the mutant gene. For so-called recessive diseases, such as Lupski's, it takes two defective copies to do the damage. This concept has dominated the study of human genetics for decades. But as more people have their genomes sequenced, and researchers and physicians begin to look more closely at the genes linked to specific disorders, it's becoming clear that Mendelian genetics isn't black and white. Genetic variations once thought to follow Mendelian rules may in fact behave in a more subtle and complicated way.

For instance, analysis has revealed that Lupski carries two copies of mutations in each of four genes linked to other Mendelian disorders. According to traditional thinking, he should suffer from all four. But he does not. The findings may turn out to be an error in sequencing, but more likely, they suggest that these mutations don't work the way researchers have assumed. Now the researchers are being forced to conclude that mutations in genes linked to Mendelian diseases don't always guarantee those disorders.

It's also turning out that carriers of recessive diseases—those who have inherited a single copy of the disease-linked mutation—may not be wholly unscathed, as Mendelian theory says they should be. Previous studies have shown that people with a single copy of the defective gene that causes cystic fibrosis are more likely than people with two copies of the normal gene to suffer from chronic sinusitis and pancreatitis. The DNA from Lupski's family fits a similar pattern.

Twenty years ago, when he was collecting the family DNA samples, Lupski had his relatives undergo a common test for neurological disease in which physicians attach electrodes to the upper arm and measure the speed of an electrical signal sent down to the wrist. Thanks to his new genetic insights, Lupski now realizes that this test revealed nerve impairment in siblings who did not have Charcot-Marie-Tooth but had inherited a single defective gene from their mother. This type of dysfunction is linked to carpal tunnel syndrome, a common disorder often caused by repetitive hand movements. The findings hint that a single mutant copy of this gene makes people more susceptible.

If the variant is indeed linked to carpal tunnel syndrome, it probably explains only a tiny percentage of cases; the genetic defect involved in the Lupskis' disease is rare. But the finding illustrates how studies of rare genetic diseases may also shed light on more common ones. Perhaps a number of different mutations, each one rare on its own, can all give rise to the set of relatively common symptoms that characterize carpal tunnel syndrome.

This notion falls in line with a shift in thinking among geneticists. Until recently, the role of genes in common diseases like Alzheimer's and type 2 diabetes was thought to be very different from the one they play in Mendelian diseases. The predominant theory was that these disorders were triggered by a number of common genetic variations, each individually exerting a relatively minor effect. Over the last five years, scientists have used microarray chips designed to quickly and cheaply detect a million or more of the most common genetic variations in hundreds of thousands of people with a variety of diseases.

But the effort has failed to identify most of the genetic basis for many diseases. So scientists are increasingly concluding that the common-variant hypothesis is wrong, and that rare variants play an important role in common diseases. If so, the best way for scientists to understand the genetics of common diseases will be to take the same approach they are now using to study rare disorders. They will need to sequence the entire genomes of patients and their families.

BETTER MEDICINE

On the second Tuesday of every month, Lupski meets with other clinical geneticists at Baylor to discuss challenging cases. Short video clips of children with a range of strange and disturbing disorders are projected on a screen in the front of the room. One boy has widely set eyes, each a different color, and hearing loss in one ear. One toddler won't put anything in his mouth and must use a gastric feeding tube. Three brothers suffer from mental retardation of unknown cause. For parents whose children's mysterious disorders haven't been identified by traditional genetic testing, genome sequencing might finally bring a diagnosis, and years of medical testing could come to an end.

In a few lucky cases, it could lead to treatment. Last year, researchers at Yale University probably saved the life of a five-month-old infant in Turkey who'd been admitted to the hospital with the catch-all diagnosis of "failure to thrive." Physicians suspected a kidney disorder. But by sequencing his exome, the portion of the genome that codes for proteins, researchers discovered a genetic mutation linked to congenital chloride diarrhea. This rare disorder can be treated by simply replacing the body's lost salt.

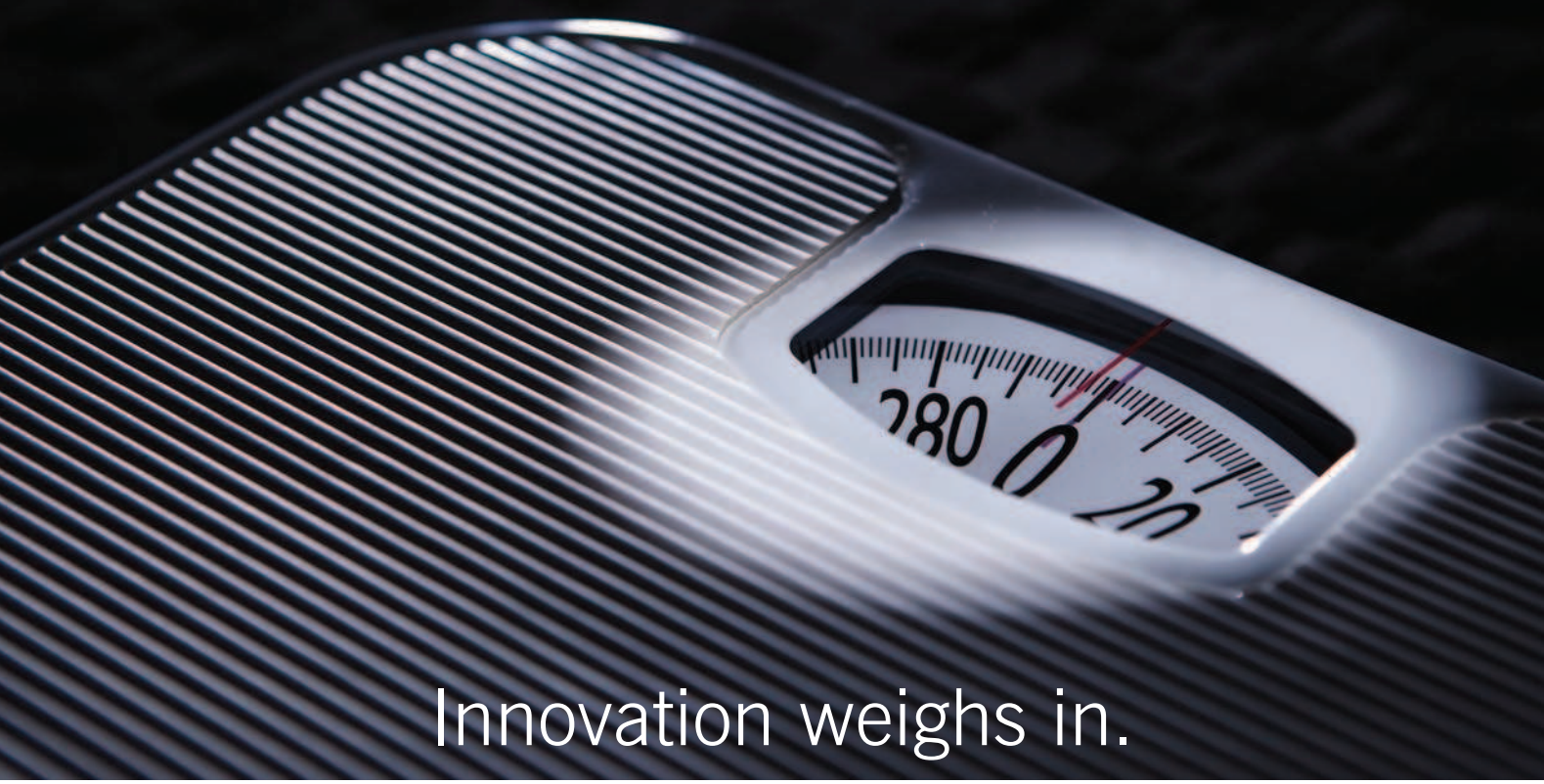
In most cases, we're still years away from cures or drugs for the genetic disorders uncovered by sequencing. Still, understanding the genetic causes of a disease is a first step to identifying its molecular mechanisms, which in turn will help researchers develop treatments. And sequencing can greatly speed up the search for disease genes. Once Lupski identified the first genetic variation for Charcot-Marie-Tooth in 1991, researchers used genetic engineering to re-create that mutation in mice and then used those animals to test potential treatments. A drug that emerged from this research is now in clinical trials for Charcot-Marie-Tooth patients who have the duplication that Lupski discovered (it turns out that about 70 percent of sufferers do). He hopes this success can be repeated for rarer disease-linked variations like his own. Another lab has already developed a mouse with a mutation in the SH3TC2 gene.

The best way for scientists to understand the genetics of common disease will be to take the same approach they are now using to study rare disorders. They will need to sequence the entire genomes of patients and their families.

As the price of sequencing continues to plummet, Lupski believes, genetically guided diagnosis will spur a major transition in medicine by helping to spotlight the complex genetics behind both rare and common diseases.

"At one point, if you had a cough, the doctor said you had pneumonia," he says. "Now we can distinguish between bacterial and viral pneumonias, and prescribe the right drug for the right type." TR

EMILY SINGER IS *TECHNOLOGY REVIEW*'S SENIOR EDITOR FOR BIOMEDICINE.



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Christopher "moot" Poole created 4chan, an online community where people are free to be wrong. Now big investors want a piece of his ideas.

Radical Opacity

By JULIAN DIBBELL

Christopher Poole is 22 years old, and as is often true for men his age, his mental life has been punctuated by a series of passing enthusiasms: video games, online chat rooms, Japanese animation. Currently he seems to be going through a Robert Moses phase. On the nightstand in his New York City apartment is a copy of *The Power Broker: Robert Moses and the Fall of New York*, a 1,300-page biography of the mid-20th-century urban planner who, in pursuing his vision of a modernized New York, destroyed one neighborhood after another. A book of photos on Poole's coffee table documents the Moses-era demolition of midtown Manhattan's vast and graceful old Penn Station. ("Gut-wrenching," says Poole.) And on a recent Thursday afternoon, as he walked to work past Washington Square Park and observed the sweeping renovations under way there—a controversial relandscaping imposed by current city planners in the face of heavy local opposition—he saw parallels with the old autocrat's imperious approach to such projects. "Robert Moses is probably smiling," he said. "Like, 'Fuck the people—what do they know!'"

Like many people, Poole thinks there are better ways than Moses's to manage the tangled social, cultural, and infrastructural needs of a community of millions. But unlike most people—let alone most 22-year-olds—he actually has some experience doing just that. Seven years ago, Poole created the website 4chan, an online community that now has nearly 11 million monthly users and is, in some respects, as unruly as any metropolis. The site is what's known as an image board, a type of online message forum that encourages users to post both images and text, and its users now contribute more than a million messages a day, their content tending in the aggregate toward a unique mix of humor, pornography, offensiveness, and, at times, borderline legality. It has long been one of the largest message forums in the world, but Poole, the only owner 4chan has ever had, continues to run it as he has always done: in his spare time, with a little help from online volunteers and just enough advertising revenue to cover bandwidth costs.

Visited mostly by young men in their late teens and early 20s, 4chan is loosely organized by topics of interest—music, games, TV, animation (Japanese and otherwise). But nearly half its messages are posted in a single random-topics section known as /b/, and /b/'s anarchy sets the tone for the site in general. It's out of /b/ that swarms of gleeful online troublemakers—trolls, in Internet parlance—occasionally issue forth to prank, hack, harass, and otherwise digitally provoke other online communities and users. From /b/, as well, the Internet at large absorbs a steady stream of catchphrases and sight gags—LOLcats, rickrolling, and other ubiquitous Internet memes that seep up from the endless, dizzying churn of /b/'s vast reservoir of inside jokes. Often intended to shock, shot through with racism, misogyny, and other qualities deliberately chosen from beyond the contemporary pale, the words and images of /b/ have become an online spectacle: "Lunatic, juvenile ... brilliant, ridiculous and alarming," the *Guardian* newspaper's website once called it. "The id of the Internet," it has been called more than once.

By no coincidence, 4chan stands out not only for the content its users generate but for the way they generate it: with a degree of anonymity almost unheard-of in the online world. Though Poole himself is known to the site's users by the cryptic pseudonym "moot," on 4chan even using a pseudonym is rare. The site has no log-in function, so each message can be posted under whatever name its author chooses, but users are strongly encouraged to

Photographs by JORDAN HOLLENDER

IN SHADOWS
Christopher Poole is the creator of 4chan, an online message board where anonymity reigns.

post with no identifying name at all. Roughly 90 percent of all messages on 4chan are posted under the site's default identity, "Anonymous." And those messages are not only anonymous but ephemeral, because 4chan has no long-term archives: old message threads are automatically deleted when new ones need the room. This mechanism was originally meant to save storage costs, but as Poole notes, "it's both practical and philosophical." Among other things, it challenges the idea that digital identity should follow you across time, linking what you say when you're a teenager to the middle-aged business owner you might become. In 4chan's heavy traffic, a message can vanish within hours or even minutes of its posting.

As approaches to community management go, this is pretty much the opposite of what the mainstream Internet seems headed toward. Anonymity, once thought to be a defining attribute of online interaction, is nowadays widely approached as a bug to be fixed. Managers of newspapers' online comment sections in particular have grown wary of it, blaming the irresponsible mentality of anonymous commenters for bitter flame wars and rambling digressions. Several newspaper sites have lately closed their comment sections to anonymous posting altogether, and at least one now requires commenters to post under their own verified credit-card billing names. But the clearest demonstration of the Internet's move away from anonymity has been the rise of social-networking sites like Facebook, whose appeal to both users and marketers rests on a closing of the gap between online and offline identities. Facebook's 26-year-old CEO, Mark Zuckerberg, seems to be an unusually fervent believer in the virtues of "radical transparency" in online dealings—he famously once told an interviewer that "having two identities for yourself is an example of a lack of integrity"—but he is not alone among the Silicon Valley elite in linking the decline of anonymity to the promise of a more tolerant, peaceful, and profitable digital world.

Yet many, even among that same Silicon Valley elite, have found reasons to regret the loss of anonymity online. Poole's selection as a speaker at the technology world's invitation-only TED conference last February provided him with an opportunity to express those reservations. Standing in sneakers and a zippered hoodie on the expensively designed TED stage (the same one Bill Gates would be speaking from the next day), Poole gave a brief talk that was as thoughtful and polite as 4chan can be rude and unhinged, and he made a compelling case for the anonymity that helps make 4chan what it is. Support for anonymous communication often comes down to a standard set of arguments: people should have a place where they can speak truth to power (blow a whistle on corruption, assess whether an emperor has clothes) without fear of reprisal; they should also have a place where they can be true to themselves (explore an unconventional sexuality, seek treatment for a stigmatized disease) without risking ostracism and worse. But while Poole embraces these arguments, what he says in defense of the anonymity on 4chan is at once less high-minded and (in ways he is only slowly coming to understand) more far-reaching:

"People deserve a place to be wrong."

MEME FACTORY

Poole didn't particularly want 4chan to be anonymous when he started it. He was 15, an only child of divorced parents, living with his mother in a Westchester County suburb of New York City and gripped by a midadolescent fascination with Japanese animation, or anime. That had led him to a good place to find anime images: the Futaba Channel, a popular Japanese image board also known to its English-speaking fans by its Web address, 2chan.net.

One of the things that struck Poole was that the site let people post in its discussion forums exceptionally quickly. It didn't especially register with him that Japan also happened to be a place where cultural distinctions between public and private life matter deeply—where, in a sense, having two identities isn't so much a failure of integrity as a working definition of it. Nor did the related facts that Japan's Internet users tend to have a particularly deep-rooted attachment to online pseudonyms and other alternate identities (as Facebook, still struggling to crack the Japanese market, has learned the hard way) or that the Futaba Channel, like most Japanese image boards, has always offered fully anonymous posting with no log-in required. None of this was what compelled him to grab a copy of the Futaba Channel's source code, rewrite the site's text in English (guessing at some of the Japanese words' meanings, running the rest through the translation engine Babel Fish), and start operating it as 4chan in October 2003. Poole recalls how Babel Fish translated the kanji signifying Futaba's default username: "Nameless." He changed it to "Anonymous," and that, more or less, was that.

"It wasn't a principled decision," says Poole. Not at first. "It became one, as I grew from 15 to 18 to now 22 .... But as a 15-year-

With its acceptance of anonymity, 4chan is pretty much the opposite of where the mainstream Internet seems headed. Social-networking sites such as Facebook are trying to close the gap between online and offline identities.

old, I wasn't too concerned with a lot of the things I really stand for now. I kind of grew into that."

4chan kind of grew into it, too. In the beginning, the site had only two topic sections: /a/ for anime-related posts, and /b/ for everything else. In subsequent years Poole gradually added topics, and there are now nearly 50 of them, including /v/ for video games, /fa/ for fashion, /po/ for paper craft and origami, and at least three for specialized varieties of Japanese cartoon erotica and porn. But /b/ has grown more steadily than any of the others, and it long ago surpassed anime as 4chan's principal reason for being. As the one section without any explicit rules about what can and can't be posted (other than certain sitewide prohibitions against child pornography and other violations of U.S. law), /b/ is where 4chan makes good on what its anonymity promises: the freedom to say anything without the obligation to suffer consequences.

To a first-time visitor, /b/ may not seem very promising at all. Aside from the sheer quantity of tastelessness that courses through its message threads, they present a wall of endlessly recycled inside references, catchphrases, and fragmentary punch lines, the briefest sampling of which will baffle: "herp derp," "newfag," "over 9000!," "So I herd u liek Mudkips," "serious business," "The Game (you just lost it)," "an hero," "Candleja—." Much harder to convey, though, is the improbable awesomeness of what /b/ reveals to those who come to know it better: the flashes of inspiration and deranged wit that flicker continually as /b/'s anonymous millions—the /b/tards, as they call themselves—work and rework variations on the esoteric routines. As this compost heap of in-jokes ripens, sometimes one of them will vault into popularity as a broader Internet meme (the most visible recent example, perhaps, is Pedobear, a creepy, vacant-eyed cartoon teddy bear whose picture is used to ridicule seekers of child pornography).

4channers have a word for all this: lulz, which in its strictest sense means laughs, jest, cheap amusement, but in a broader sense encompasses both the furious creativity that generates /b/'s vast repertoire of memes and the rollicking subcultural intensity they inspire. And if 4chan's anonymity is good for anything, it turns out, it's good for lulz. Consider, Poole explains, how the fixed identities in other online communities can stifle creativity: where usernames are required (whether real or pseudonymous), a new user who posts a few failed attempts at humor will soon find other users associating that name with failure. "Even if you're posting gold by day eight," says Poole, "they'll be like, 'Oh, this guy sucks.'" Names, in other words, make failure costly, thus discouraging even the attempt to succeed. By the same token, namelessness makes failure cheap—nearly costless, reputation-wise, in a setting like 4chan, where the Anonymous who posted a lame joke five minutes ago might well be the same Anonymous who's mocking it hilariously right now. And as the social-media theorist Clay Shirky has suggested in another context (explaining how the plummeting costs of networked collaboration encourage, say, a thousand open-source software projects to launch for every one that gets anywhere), the closer a community gets to "failure for free," the better its chances of generating success.

That may not be the only thing Poole meant when he talked at TED about 4chan's importance as a place to be wrong. But it's ultimately the reason he was on that stage, and it's starting to look like the reason he'll be in a spotlight for a while to come.

4CHAN INTO FORTUNE?

On May 13, 2010, just after the end of his sophomore year in college, Poole filed notice with the Securities and Exchange Commission about an extracurricular activity: raising $625,000 for a new online venture. The time had come, he felt, for something like a reboot. After seven years of administrative and technological tweaks to 4chan, he no longer sees it as a project much in need of his creative attention. Meanwhile, he notes, Web technology has evolved far beyond 4chan's "decade-old code and decade-or-two-old paradigm"—that of the classic pre-Web bulletin board—and he is eager to reimagine what a modern discussion forum can be. The name of the new site is Canvas, and Poole hopes to launch it this fall. People will have the option of signing in, although Poole says he hopes to keep Canvas relatively free of "vanity and ego." As on 4chan, users will be able to post comments anonymously and to switch fluidly between multiple identities.

It says something that investors in Canvas—who include Marc Andreessen (creator of the first graphical Web browser) and Ron Conway (an early Google backer)—would bet on a track record like Poole's. For all of 4chan's eye-popping traffic stats, it's doomed to bare-subsistence revenue by the combination of its scandalous content (palatable only to low-rent advertisers like porn sites) and Poole's profound discomfort with, as he puts it, the "tons of ways I could essentially rape the site for dollars" (including pop-ups, ads with sound, and other high-paying but obnoxious forms of advertising that would antagonize 4chan's community). And whether it was the 2006 "dirty bomb" incident, in which 20-year-old Jake Brahm flooded /b/ with threats to detonate radioactive explosives at NFL games, or the harrowing of Jessi Slaughter this July, in which the troll hordes of /b/ rained death threats and other anonymous harassment on an 11-year-old Florida girl, the portrayal of 4chan in the national news has mainly reflected the image of a menace to be contained rather than an enterprise to watch.

And yet, many in the Internet business *have* been watching 4chan with interest. The steady growth of its traffic and the viral spread of its content, after all, represent the kind of social success that Web businesses require. "Getting engaged users is the tough part," says David Lee, who invested in Canvas as a partner in Conway's SV Angel firm. Profit or no profit, he explains, 4chan shows that Poole "is the rare entrepreneur who can get engaged users." And given how firmly anonymity is held to be a recipe for social-media failure, it's intriguing that the site works at all. 4chan "was a thing that challenged people's assumptions in the Web industry," says Jonah Peretti, CEO of the viral-media startup BuzzFeed and cofounder of the Huffington Post. "It was just so different from the way other people were thinking about community."

This year Poole got an official invitation to speak to developers at Facebook's headquarters in Palo Alto, CA. He was asked about his experiences running a site that Ruchi Sangvi, the Facebook product manager who proposed the visit, calls "the polar opposite" of their own. Roughly 80 Facebook employees attended, squeezing into a standing-room-only conference room, and though there was some trepidation at first—some Facebookers expected Poole to be an apologist for hackers and child porn—by all accounts the visit was cordial. "He's a really, really smart guy with a great vision," says Richard Cho, a Facebook recruiter who helped organize the event. In fact, Cho says Poole is "not dissimilar to Mark Zuckerberg," in that both have "interesting viewpoints" about how people connect and share information. But there was also a simpler reason for Facebook's sympathy for the man behind 4chan: "There are some of us that have frequented that site quite a bit," Cho says. "'I can has cheezburger?' is just a common part of our vernacular internally."

The radical transparency of Facebook may not be mutually exclusive with what we might as well call the radical opacity of 4chan. Their uses may even be mutually necessary.

After all, the radical transparency of Mark Zuckerberg and Facebook may not be mutually exclusive with what we might as well call the radical opacity of Christopher "moot" Poole and 4chan. Their uses may even be mutually necessary. Peretti puts it this way: if 4chan is the id of the Internet, then "Google is kind of like the ego, and Facebook is kind of like the superego." If that's so, then there's only one way the trend toward radical transparency won't end up killing the Internet's soul: if we can leave the light of all that openness every now and then to spend some time in the shadows where the crazy lives. TR

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BRIEFING: FUELS

A drilling rig seeks oil 140 miles off the coast of Louisiana.

PAUL TAGGART/WPN

INTRODUCTION

Fossil Fuels Remain a Mainstay

Scientists generally agree that to limit global warming to less than 2.4 °C—and avoid the worst effects of climate change—greenhouse-gas emissions must be reduced 50 percent by 2050. But humanity is a long way from being weaned from the petroleum, natural gas, and coal whose use causes much of this pollution.

In fact, global energy demand is expected to increase about 40 percent over the next two decades. By 2030, the use of petroleum, coal, and natural gas is expected to jump by 23 percent, 44 percent, and 37 percent, respectively. "You look at the world of renewables and you see a lot of progress, but they are not going to outpace the growing demand for energy," says Peter Jackson, a senior director at IHS Cambridge Energy Research Associates, an energy consultancy and think tank.

The near-term challenge, therefore, is to find ways to extract fossil fuels safely and use them in ways that emit as little carbon dioxide as possible. But dwindling supplies in conventional oil fields are forcing the petroleum industry to drill in deeper waters and pursue hard-to-extract deposits such as the tar sands of Alberta, Canada.

In the next decade, some oil can be replaced by ethanol: U.S. producers will make about 12 billion gallons of it from corn this year. But that's a small fraction of the roughly 170 billion gallons of gasoline and diesel that will be consumed in 2010. Making biofuels at a significantly larger scale will mean using cellulosic biomass as a feedstock for ethanol and other fuels, and deriving fuels from custom-engineered microbes.

Coal, the dirtiest fossil fuel, accounts for 42 percent of electricity production worldwide and 45 percent in the United States. The good news is that natural gas is far more abundant than was thought only a few years ago. And replacing coal plants with natural-gas plants could greatly reduce carbon dioxide emissions.

—David Talbot

This jar contains a sample of switchgrass, one type of cellulosic feedstock.

TECHNOLOGY OVERVIEW

Making Cellulosic Biofuels Competitive

As long as electric vehicles remain a niche, biofuels will be the most serious alternative to fossil fuels as a way to power cars and trucks. Millions of existing vehicles can run on fuels mixed with high concentrations of ethanol or biodiesel. The rest, hundreds of millions more in the U.S., can run on mixtures that include some ethanol.

Making vast quantities of biofuels without cutting into food supplies, however, means finding a way to use wood chips, corn stalks, and other forms of cellulosic biomass as feedstocks. Dozens of pilot and demonstration-scale plants for producing cellulosic ethanol have been built across the United States, and a few are planned abroad, including some in China. But it's still not clear when the technology will prove competitive.

Most approaches to making cellulosic biofuels require enzymes to break down cellulose into simple sugars, but these enzymes are expensive. Some companies have developed cheaper ones—Denmark-based Novozymes, for example, says it has lowered the cost by 80 percent over the past two years—while others are engineering microbes to create their own. An organism developed by Qteros, in Marlborough, MA, produces enzymes that convert cellulose into sugar and then turns that sugar into ethanol.

Another strategy is to try to get rid of the enzymes altogether. For example, Coskata, based in Warrenville, IL, uses gasification technology to break down biomass and municipal waste into carbon monoxide and hydrogen. It has developed organisms that can feed on this mixture and produce ethanol.

Other companies are trying to make fuels that resemble gasoline or diesel. BP and DuPont are developing a process for turning cellulose into butanol, an alcohol with properties similar to those of gasoline. LS9, in South San Francisco, has used synthetic biology to design organisms that can process sugars into something "essentially indistinguishable" from petroleum-based fuels such as diesel.

But these companies also need to build large biorefineries capable of producing fuels as cheap as gasoline, which has production costs of around $2.00 a gallon. The latest public data suggest that it costs between $3.00 and $4.50 to produce cellulosic ethanol that matches the energy content of a gallon of gasoline. The figure for corn ethanol is $2.40.

—Kevin Bullis

DATA SHOT

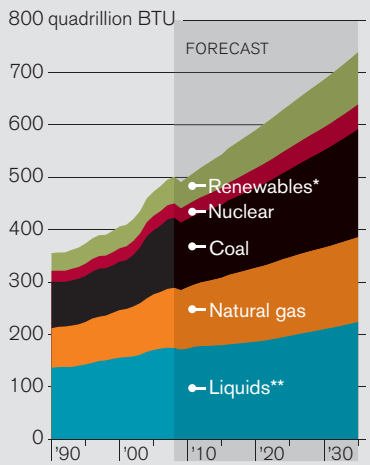
387

Average parts per million of carbon dioxide in the atmosphere, as measured by Mauna Loa Observatory, in Hawaii, in 2009. The level has increased 71 parts per million since 1959.

SURGING DEMAND

A mix of fuels will meet the world's energy needs over the next 25 years.

Total world energy use by fuel type
(1990–2035)



**Includes hydroelectric, solar, wind, geothermal, biomass, and tidal.*

***Includes all biofuels; all liquid fuels derived from petroleum, gas, and coal; and liquid hydrogen.*

Source: U.S. Energy Information Administration

CHARLIE NEIBERGALL/AP; ALL CHARTS BY TOMMY MCCALL

INDUSTRY CHALLENGES

The End of Easy Oil

The world won't run short of petroleum in the next few decades, but there's a limited supply of easy-to-reach oil. Between now and 2030, production from such "conventional" sources will barely rise—from 79 million to 85 million barrels per day.

During the same period, demand for liquid fuels is expected to rise from 86 million to 106 million barrels per day. While more than half of that extra demand will be met by other sources, such as biofuels and fuels derived from coal or natural gas, the petroleum industry will have to make up the rest from harder-to-extract oil supplies.

To get at this oil, companies will drill in deep waters to tap reserves below the ocean floor. By 2030, the production of oil from waters deeper than 600 meters will increase from five million to 10 million barrels per day. This year's disaster in the Gulf of Mexico—where BP was drilling at a depth of 1,500 meters—highlights the risks involved.

And petroleum companies will increasingly turn to unconventional sources such as tar sands. The largest of these molasses-like deposits are in Canada and Venezuela, whose combined resources of this type are believed to exceed the total world resources held in conventional oil fields. Production from these areas is projected to rise from 2.3 million barrels per day at present to 5.5 million barrels per day in 2030, according to a study by Cambridge Energy Research Associates, an energy consultancy.

That increase will meet about 16 percent of the total demand, but at the cost of a disproportionate environmental impact. It takes huge amounts of energy to extract and process tar sands, generating two to four times the greenhouse gases associated with conventional petroleum production.

As oil gets harder to find, prices may rise, which will make riskier exploration more worthwhile and also boost alternatives, including advanced biofuels. But a price on carbon emissions could change the calculus, making tar sands particularly uneconomical. *—David Talbot*

A worker holds a blob of tar sands from a mine in Alberta, Canada.

LARA SOLT/CORBIS

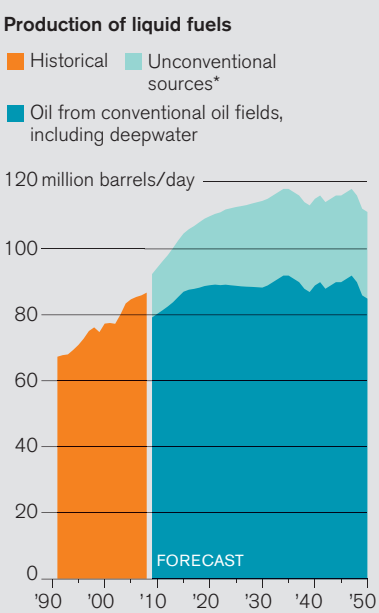
DATA SHOT

$1.78

The cost per gallon to U.S. taxpayers of subsidies aimed at replacing gasoline with conventional corn ethanol, according to the Congressional Budget Office.

SOURCES OF FUEL

Hard-to-extract oil, and oil alternatives, will make up a growing share.



**Includes coal- and gas-to-liquids, biofuels, liquid natural gas, and tar sands.*

Source: IHS Energy Research Associates

CASE STUDY

Mascoma: Seeking a Market Toehold

When the biofuels startup Mascoma launched in 2005, it hoped to capitalize on technology that would produce ethanol from wood chips and other plant waste in an efficient one-step process.

Mascoma secured $30 million in financing by 2006 and began building a 200,000-gallon–per-year pilot plant in Rome, NY, the following year. In 2008, the company heralded new research advances toward genetically engineered bacteria that could thrive at high temperatures. Using them made it possible to reduce by 60 percent the quantity of costly enzymes needed to degrade cellulose into fermentable sugars. The company announced plans to build one of the first commercial-scale cellulosic-ethanol plants, in Kinross, MI; it would be able to produce 80 million gallons per year.

But as of the summer of 2010, Mascoma had yet to begin construction. Simply put, nobody would lend it the money for a production plant whose product would compete with relatively cheap oil. "The bottom line is, these are high-risk, first-of-kind plants," says Mike Cleary, director of the National Bioenergy Center at the National Renewable Energy Laboratory in Golden, CO. "Getting banks to loan them money is hard."

Mascoma received $49.5 million from the U.S. Department of Energy and the state of Michigan to finance its cellulosic-ethanol operations, and that funding has been earmarked for the Kinross plant. But Alan Belcher, Mascoma's senior vice president of operations, says the company would need more than $100 million to build that facility.

A viable future for cellulosic ethanol will require changes in government policy, says Belcher. An existing federal mandate caps the amount of ethanol blended with gasoline in auto fuel at 10 percent of the total mixture. Existing production capacity for corn ethanol can already meet the resulting demand, which amounts to 13.5 billion gallons a year. Right now, there's really no room for any more ethanol on the market, no matter how it's produced. At the least, the blend limit must be raised; then a different set of federal mandates, dictating minimum use of advanced biofuels such as cellulosic ethanol, can kick in and provide a market for Mascoma's product, Belcher says.

Mascoma currently hopes to break ground at Kinross in 2011. The goal is to begin production at 20 million gallons of ethanol per year, using 500,000 tons of hardwood pulpwood as feedstock. But to get there, great technology simply won't be enough. —*Nidhi Subbaraman*

Mascoma's cellulosic-ethanol pilot plant in Rome, NY, showed that a promising technology worked. But a shortage of investors has hampered plans for a commercial-scale plant.

COURTESY OF MASCOMA

RESEARCH TO WATCH

Building Microbial Fuel Factories

Viewed from a biofuels perspective, biological plants waste huge amounts of energy: they use sunlight to make cellulose, starch, lignin, and seeds, some of which can then be broken down and converted into fuels. A growing body of research is seeking to genetically engineer organisms to make liquid fuels directly. Organisms optimized in this way could theoretically be an order of magnitude more efficient than technologies that make fuels from biomass.

Joule Unlimited, a startup based in Cambridge, MA, is genetically altering photosynthetic microörganisms so that over their lifetime, they devote only 5 percent of the solar energy they absorb to growing and staying alive. The rest goes to secreting a steady supply of diesel fuel. The company, which is building a pilot plant in Leander, TX, says its process will generate 15 to 25

Grow lights illuminate flasks of photosynthetic microörganisms that produce biofuels.

BOB O'CONNOR

times as much fuel per acre as technology for making fuels from cellulosic biomass, but that it will take several years to demonstrate at a large scale. Synthetic Genomics, with funding from ExxonMobil that could exceed $300 million, is taking a similar approach, working with algae.

To replace all petroleum with biofuels, however, it might be necessary to genetically engineer organisms that get energy through potentially more efficient mechanisms. And the U.S. Department of Energy's Advanced Research Projects Agency–Energy (ARPA-E) is funding 13 projects that are engineering organisms to convert electricity and hydrogen—ideally from renewable sources—into liquid fuels for conventional cars. *—Kevin Bullis*

DATA SHOT

77%

The growth in the estimated amount of recoverable U.S. natural gas since 1990, thanks to new approaches to drilling in unconventional deposits.

NATURAL GAS

Tapping an Unconventional Source

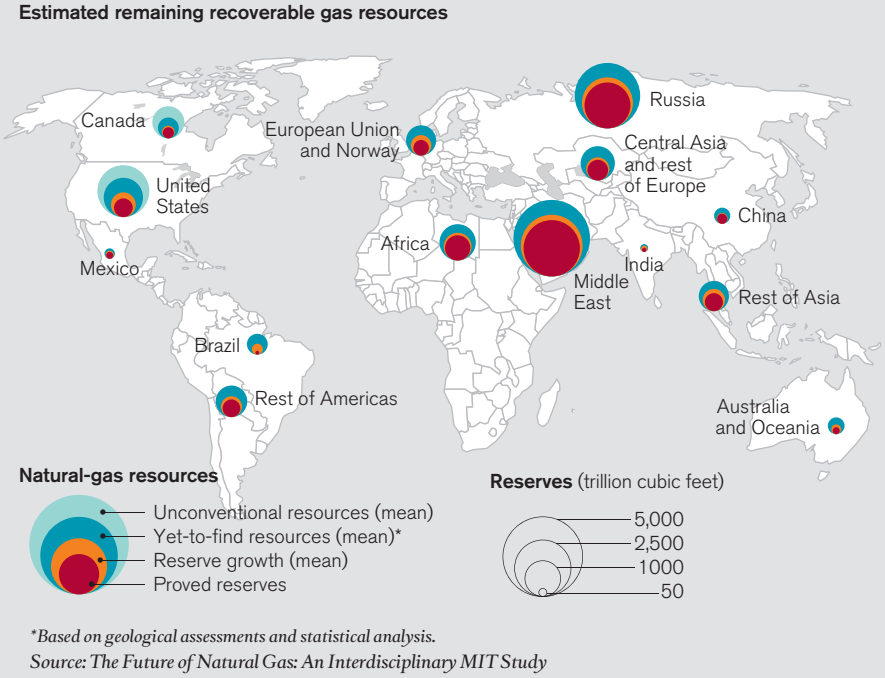
In recent years it has become clear that the United States and Canada hold a bonanza in recoverable natural gas, a resource once thought to be declining. Because natural gas releases just half as much carbon dioxide as coal when it's burned to produce a comparable amount of electricity, the fuel could play an important role in reducing carbon emissions.

In the United States, for example, 45 percent of electricity comes from coal and 23 percent from natural gas. If half the electricity from coal were replaced with electricity from natural gas, it would eliminate 20 percent of the U.S. carbon dioxide emissions attributable to electricity generation.

Much of the optimism stems from the discovery that natural gas can be extracted economically from vast deposits of shale found across the United States *(see "Natural Gas Changes the Energy Map," November/December 2009)*. At current rates of consumption, those resources alone could meet U.S. demand for decades. Known worldwide supplies of natural gas add up to 150 times annual global consumption, and this estimate doesn't include unconventional sources outside North America. *—David Talbot*

RISING ESTIMATES ON NATURAL GAS

Estimates of recoverable natural gas from unconventional sources in the United States and Canada have risen sharply; data is lacking on such sources elsewhere.



*Based on geological assessments and statistical analysis.

Source: The Future of Natural Gas: An Interdisciplinary MIT Study

The Shenhua coal-to-liquids plant pumps out a million gallons of diesel fuel per day and may start burying carbon dioxide, too.

CHINA

Beijing Sees Future in Liquefied Coal

With a shortage of domestic oil and an automobile market that's now the world's biggest, China has begun a large-scale program to transform its abundant coal resources into motor fuels. It's already home to the world's largest coal liquefaction plant—a facility in Inner Mongolia that reached its full capacity last year and can now pump out a million gallons of diesel fuel per day.

The plant made China only the second country in the world, after South Africa, to successfully derive liquid fuels from coal on a commercial scale. Built by coal producer Shenhua Group, the facility uses the heat and hydrogen generated by gasifying a small amount of coal to brew a wet slurry made from a second stream of coal into diesel fuel. The process makes economic sense but inflicts an environmental double whammy. Simply making the fuel produces prodigious amounts of carbon dioxide, even before the fuel itself is burned. It also uses enormous amounts of another scarce Chinese commodity: water.

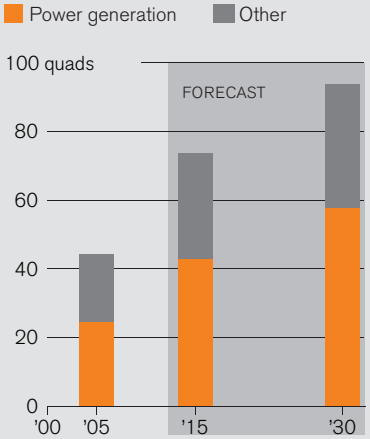
Despite these negatives, China will keep pursuing the technology. "They do not have a better way to meet this need," says Qingyun Sun, a coal-to-liquids expert at West Virginia University. Indeed, Shenhua Group is planning to quintuple its coal-to-diesel capacity by 2013. And that company is not the only player involved.

Other Chinese plants are turning coal into methanol and catalytically synthesizing gasified coal into a variety of chemical commodities. Since 2007, Chinese fuel marketers have been blending a billion gallons or more into gasoline at the pump. To try to mitigate emissions, Shenhua has started a small carbon sequestration project that is expected to inject 100,000 tons of carbon dioxide into a deep saline aquifer by the end of this year. Its vast plant can potentially capture 2.9 million tons of carbon dioxide annually—about four-fifths of the plant's emissions. —*Peter Fairley*

COAL-HUNGRY CHINA

Despite the prodigious carbon emissions associated with coal, Beijing is digging deeper.

Coal consumption in China (2000–2030)



Source: CCIDRC

OVER THE HORIZON

The Quest to Sequester

One way to continue using coal and other fossil fuels without promoting catastrophic climate change would be to capture the carbon dioxide released by burning them and then pump it underground for permanent storage, a process called carbon sequestration.

This strategy has been demonstrated in a few places. But for it to make a significant impact on carbon emissions, researchers must find economical ways to capture the gas, plus practical ways to liquefy and bury billions of tons of it each year—and keep this up for decades. The need is staggering: coal accounts for 20 percent of all greenhouse-gas emissions worldwide. In the United States, for example, 600 coal-fired power plants emit two billion tons of carbon dioxide annually. China's coal emissions are roughly double that amount and growing rapidly.

The first problem is capturing the gas. Right now, retrofitting existing power plants with carbon dioxide scrubbers will eat up a quarter of the energy the plant produces. Jared Ciferno, who specializes in carbon capture technology at the

US-CHINA ENERGY CENTER, WEST VIRGINIA UNIVERSITY

U.S. Department of Energy's National Energy Technology Laboratory, says this loss needs to be cut to 18 percent to make post-combustion carbon dioxide capture economically viable.

Alternative processes exist: coal can be turned into a combustible gas, which produces a purer stream of easier-to-capture carbon dioxide when it's burned. However, gasification plants cost more than coal-burning ones. A few of these are under construction in Indiana, Pennsylvania, and Tianjin, China, but they would not be cost-effective without government incentives.

Then there's the problem of burying the carbon dioxide. Here, there is some good news: many major coal-burning countries and regions, including the United States and China, are believed to have geological features suitable for sequestration, especially deep saline aquifers that sit beneath multiple layers of rock to keep carbon dioxide safely trapped. What's more, where sequestration has been tried, geologists report that the carbon dioxide hasn't leaked, even in regions where decades of oil drilling have perforated underground rocks.

However, there are still no financial or regulatory incentives for power producers to pursue carbon sequestration. It's unlikely that the technology will get very far without, for example, a tax or other mechanism for putting a price on carbon. Says Julio Friedmann, director of Lawrence Livermore National Laboratory's Carbon Storage Initiative, "We need incentives to get the sequestration market moving."—*Peter Fairley*

DATA SHOT

89%

The worldwide share of conventional ethanol produced in the United States (mainly from corn) and Brazil (mainly from sugarcane) in 2009.

ROBYN BECK/AFP/GETTY IMAGES

POLICY

Piecemeal Efforts Fall Short

Despite ongoing concerns about the United States' vast appetite for petroleum in general and foreign oil in particular, Washington has taken only piecemeal measures to address the challenge. Collectively, these efforts will have only a small impact on the amount of oil the country consumes.

In April, the U.S. Environmental Protection Agency and the Department of Transportation tightened fuel economy regulations: cars will be required to achieve an average of 35.5 miles per gallon starting in 2016, up from 27.5 today. The EPA expects this change to save 1.8 billion barrels of oil over the lifetime of the vehicles sold under these regulations. But that's only a bit more oil than the U.S. consumes in three months.

In 2007, Congress passed a bill directing fuel companies to distribute 36 billion gallons of biofuels a year by 2022. That's a small but significant chunk of the fuel supply: roughly 17 percent of annual gasoline consumption. According to the federal mandates, 21 billion gallons must be advanced biofuels rather than the biofuels that are commercially available now, such as corn-derived ethanol. The technology exists to make these new fuels, which include ethanol made from cellulosic sources such as grasses, and other fuels derived from sources such as algae. But attempts to make them in volume are off to a slow start.

A Toyota dealership in Torrance, CA, advertises the fuel economy of the hybrid Prius.

The federal mandates initially required that energy distributors use 100 million gallons of cellulosic ethanol this year, but the EPA scaled this back to 6.5 million gallons because no commercial cellulosic-ethanol plants have been built yet. The EPA plans to waive next year's even larger requirements, too. For the foreseeable future, advanced biofuels aren't going to make much of a dent in petroleum consumption. —*Kevin Bullis*

A pilot-scale biorefinery in Jennings, LA, turns agricultural waste into ethanol. BP acquired the facility in a deal with Verenium.

MARKET WATCH

Big Oil Gets Bigger

To meet the ever more challenging demands of extraction while moving toward less carbon-intensive fuels, big oil companies are diversifying. They're buying smaller companies with experience in tapping unconventional sources of oil and natural gas, and they're also making bets on biofuels.

DATA SHOT

$8.2 billion

Value of mergers and acquisitions involving the Marcellus shale, the huge natural-gas resource in the northeastern United States, in the second quarter of this year.

The first half of 2010 saw 322 oil-industry mergers and acquisitions with a value of $90.8 billion worldwide—nearly as much as the full year of deals in 2008 and on track to beat 2009, according to PLS, a research firm based in Houston.

Much of the activity was in the United States and involved unconventional resources. There were 13 deals involving the Marcellus shale, a vast deposit of natural gas in the eastern United States. Royal Dutch Shell, for example, bought East Resources for $4.7 billion, thereby acquiring 2,600 square kilometers of resources in the region. In June, ExxonMobil completed its acquisition of XTO, an independent producer of unconventional natural gas and oil, in a transaction worth $36 billion. The acquisition made Exxon the largest producer of natural gas from U.S. sources.

In July, BP decided to sell off $7 billion in oil and gas fields to Apache, in part to cover the bill for its Gulf of Mexico oil spill. This deal also showed a turn toward unconventional fossil fuels; BP decided to focus on developing its deep offshore oil resources rather than more conventional land-based resources.

The major oil companies' investments in biofuels are on a much smaller scale. This year BP bought the cellulosic-ethanol business of Verenium. The $98.3 million purchase included Verenium's 1.4-million-gallon-a-year demonstration plant, which converts leftovers from sugarcane processing (among other things) into ethanol. When it comes to biofuels, however, the major oil companies are currently focused less on acquisitions and more on research and development. ExxonMobil, for example, could end up investing more than $600 million in a joint venture with Synthetic Genomics to make renewable fuels from algae. *—Kevin Bullis*

BIOFUELS IP

In 1990 a University of Florida microbiologist, Lonnie Ingram, transferred genes responsible for ethanol fermentation to *E. coli* from another bacterium. Many of the descriptions and examples in the patent involved hemicellulosic sugars, which make up a large fraction of the sugars available in cellulosic biomass such as corn stalks and wood chips. The patent thus described a way to make cellulosic-ethanol production practical. It has been cited 23 times, including four in 2010, suggesting that it's one of the more important patents in the field.
To see IPVision's interactive analysis of Ingram's patent and its impact, go to **www.technologyreview.com/briefings/fuels**.

BRAD PUCKETT/LAKE CHARLES AMERICAN PRESS/AP

COMPANIES TO WATCH: PUBLIC

BP
Surviving the spill

www.bp.com
Founded: 1909
Management: Robert Dudley (CEO), Carl-Henric Svanberg (chairman) Phil New (CEO, BP Biofuels), Lamar McKay (chairman, BP America)
Employees: 80,300
Revenues: $246.1 billion
R&D: $587.0 million
Market cap: $129.7 billion

Technology: Now infamous for the Deepwater Horizon spill, this U.K.-based oil and gas giant is a global leader in deepwater exploration and drilling technology. It has also invested heavily in advanced biofuels. **Market:** In addition to being one of the world's leading producers of conventional oil, BP is one of the largest distributors of biofuels. It blends over a billion gallons of ethanol a year in the United States, a market that will only grow: the country's Renewable Fuel Standard calls for 36 billion gallons of renewable fuels to be used in 2022. **Strategy:** In 2008, BP invested in a sugarcane-ethanol venture in Brazil, and the company has a major stake in another ethanol refinery currently under construction in the U.K. It recently acquired a million-gallon-per-year cellulosic-ethanol facility from the startup Verenium; it is also collaborating with DuPont to develop biobutanol and with a startup called Martek Biosciences to develop microbial biodiesel. **Challenges and next steps:** The Gulf of Mexico was one of BP's main centers of deepwater operations, and its future in the region is unclear. Although BP has made significant investments in biofuels, the world's largest market for these fuels is the United States, where it now faces a public-relations battle.

China Shenhua Energy Company
Developing new uses for coal

www.csec.com
Founded: 1995
Management: Ling Wen (president), Wang Jinli (vice president of strategic planning)
Employees: 62,286
Revenues: $17.7 billion
R&D: N/A
Market cap: $82.0 billion

Technology: Shenhua is developing technology for turning coal into liquid fuels and deploying it on a large scale. The company opened China's first coal-to-liquids plant in Mongolia at the end of 2008, and late last year it broke ground on a $10 billion coal-to-chemicals plant in collaboration with Dow Chemical. It is also seeking approval for a joint venture with Sasol to build a coal-to-liquids facility that is designed to produce nearly 100,000 barrels of fuel per day. **Market:** China is oil poor but coal rich, so coal-to-liquids technology is crucial if the country is to meet its growing energy needs without relying on foreign imports. **Strategy:** As China attempts to move away from coal-fired power plants in favor of cleaner alternatives like hydropower and nuclear, the country's largest coal producer is betting that liquid fuels will be the key to its future growth. **Challenges and next steps:** In addition to producing carbon emissions, which could make operations more costly as China considers mitigation strategies, coal-to-liquids plants require huge amounts of water, making their widespread use potentially problematic in a country where a massive recent build-out of hydropower has made water rights a politically charged topic.

Duke Energy
Utility seeks a price on carbon

www.duke-energy.com
Founded: 1909
Management: James Rogers (CEO), David Mohler (CTO), Roberta Bowman (chief sustainability officer)
Employees: 18,680
Revenues: $12.7 billion
R&D: N/A
Market cap: $22.2 billion

Technology: Investments in advanced gas-fueled power plants and wind turbines are offsetting some of Duke Energy's reliance on coal, which accounts for 62 percent of the power it generates. So far, gas, hydropower, and wind account for only 7 percent of the power produced, but a total of 5,000 megawatts of wind power is in development. The company has applied for approval to build new nuclear reactors. **Market:** About four million customers rely on Duke Energy for electricity. It owns 27,000 megawatts of generation capacity in its franchised electricity business and nearly 8,000 megawatts in a commercial power enterprise. **Strategy:** Duke has become a prominent supporter of regulating greenhouse-gas emissions. It says its position is motivated largely by a desire for certainty about policy as it faces the need to replace aging power plants. **Challenges and next steps:** Congress's failure to pass comprehensive climate and energy legislation may lead the utility to add new generating capacity that, over the long term, could push emissions and electricity prices higher than they would be if clear policies had been put in place. Like some other utilities, Duke is also facing challenges getting new nuclear power plants approved and funded.

DuPont
Getting into biofuels

www.dupont.com
Founded: 1802
Management: Ellen J. Kullman (CEO), Uma Chowdhry (chief science and technology officer)
Employees: 58,000
Revenues: $26.1 billion
R&D: $1.4 billion
Market cap: $33.9 billion

Technology: In addition to developing biobutanol in collaboration with BP, DuPont is looking to commercialize cellulosic ethanol—biofuel made from sources such as stems and leaves—through a joint venture with the Danish enzyme maker Danisco. In January, the companies opened a 250,000-gallon-a-year demonstration plant in Tennessee, which uses corncobs and switchgrass as the feedstocks. DuPont provides expertise in pretreating the biomass, which makes it easier to turn cellulose into sugars. **Market:** At the facility in Tennessee, the company is already producing ethanol at a cost of less than $2.00 per gallon. DuPont believes it can drive that cost down further by refining the process as it moves toward commercial production. **Strategy:** DuPont is developing a number of clean-fuel technologies, whether by producing fuels itself or by licensing its chemical processes to other companies. **Challenges and next steps:** This fall, DuPont and Danisco are expected to announce plans for their first commercial-scale biorefinery to produce cellulosic ethanol. They also plan to license their technology to others. Like all biofuel producers, they rely on government subsidies and grants and must continue to do so until the industry gets on its feet.

ExxonMobil
Expanding into emerging markets

www.exxonmobil.com
Founded: 1870
Management: Rex W. Tillerson (CEO), Emil Jacobs (vice president for R&D, ExxonMobil Research and Engineering)
Employees: 80,700
Revenues: $310.6 billion
R&D: $1.0 billion
Market cap: $296.6 billion

Technology: In the 1960s ExxonMobil invented a system, now standard throughout the industry, that uses sound waves to draw a high-resolution, three-dimensional picture of mineral formations deep underground. The company also uses a technology it developed to discover reservoirs in ultradeep water, taking advantage of the fact that oil and gas are poor conductors of electricity. **Market:** ExxonMobil is the world's largest non-government-owned company; it is involved in oil production, refining, distribution, and retail sales. It produces over 2 million barrels of crude oil a day. **Strategy:** In addition to exploring unconventional oil and gas resources to meet the world's growing energy demand, the company is looking to advanced biofuels. It has also launched an initiative with Synthetic Genomics to develop and commercialize biofuels produced using algae; ExxonMobil expects to invest more than $600 million if benchmarks are met. **Challenges and next steps:** Although worldwide energy demand is expected to continue growing in the coming decades, oil consumption in the United States and Europe actually declined last year, because of the economic downturn. The company will have to keep expanding into emerging markets and alternative fuels.

COMPANIES TO WATCH: PUBLIC

Petrobras

Pursuing ultradeep oil and sugarcane ethanol

www.petrobras.com.br/en
Founded: 1953
Management: José Sergio Gabrielli de Azevedo (CEO), Carlos Tadeu da Costa Fraga (executive manager for R&D)
Employees: 76,977
Revenues: $91.9 billion
R&D: $681.0 million
Market cap: $166.8 billion

Technology: Petrobras is using advanced technology to drill wells off the coast of Brazil at depths of up to seven kilometers. It is developing gas-to-liquids microreactors to turn some of the natural gas that bubbles up from these offshore wells (usually treated as a nuisance) into synthetic crude. **Market:** In addition to its offshore drilling operations, the company is a major producer and marketer of sugarcane-based ethanol. Widespread use of flex-fuel vehicles in Brazil has created huge domestic demand, but the company is also hoping to quadruple its ethanol exports by 2013. **Strategy:** Petrobras owns oil and gas wells throughout the world but is now focused on developing new oil fields off Brazil's southeastern coast, which could allow the country to pass Venezuela and Mexico as the largest oil producer in the Americas. Since it is also the world's largest ethanol producer, Brazil expects that soon it will no longer need to import oil. **Challenges and next steps:** Although publicly traded, Petrobras is state run, and Brazilian president Luiz Inácio Lula da Silva recently issued new regulations on how the company will be able to exploit its offshore reserves. The Brazilian government is also drawing lessons from the BP spill. A similar accident would be disastrous for tourism.

Range Resources

Tapping natural gas in shale

www.rangeresources.com
Founded: 1976
Management: John Pinkerton (CEO), Jeff Ventura (president and COO)
Employees: 787
Revenues: $907.3 million
R&D: N/A
Market cap: $7.5 billion

Technology: In 2004, Range Resources began the first commercial drilling operations for natural gas at the huge Marcellus shale bed. It drills horizontal wells, then flushes the bores with water and chemicals at high pressure. As the water is removed, trapped natural gas is released into pipes. **Market:** With an estimated 489 trillion cubic feet of recoverable natural gas, the Marcellus shale is the second-largest known deposit of natural gas in the world. If U.S. power production shifts in the coming years from coal to natural gas, Range—which owns the rights to drill in 1.3 million acres of Marcellus deposits—will be poised to capitalize. **Strategy:** Range Resources owns natural-gas drilling rights in other regions, but for 2010 it has emphasized drilling operations at the Marcellus deposits. The company hopes to triple the number of wells drilled at the site, from 55 in 2009 to 150 by the end of this year. **Challenges and next steps:** For power producers, coal still remains the cheapest resource available, so the switch to natural gas is not inevitable. And with no refueling infrastructure for automobiles powered by natural gas, car and truck manufacturers will have little incentive to alter vehicle designs unless government policies change.

Sasol

Turning coal and gas into liquid fuels

www.sasol.com
Founded: 1950
Management: Pat Davies (CEO), Nolitha Fakude (executive director), Christine Ramon (CFO)
Employees: 34,000
Revenues: $18.3 billion
R&D: $122.6 million
Market cap: $25.1 billion

Technology: This South African oil and gas company started with a coal-to-liquids technology originally developed in Germany in the 1920s and created highly efficient processes for turning coal and natural gas into synthetic liquid fuels and a variety of chemicals. **Market:** Sasol has initiated projects in markets that will see strong growth, including India and China, where growing energy demand cannot be met entirely by new oil production. Synthetic fuels and products from more abundant coal resources can fill the gap. **Strategy:** Sasol mines its own coal at one of the world's largest coal-to-liquids facilities in Secunda, South Africa, and it's developing gas-to-liquids projects in Africa, the Middle East, and Australia. Sasol also complements its coal- and gas-to-liquids programs with conventional crude-oil production offshore of Gabon and refines imported oil. **Challenges and next steps:** Although the fuel produced in Sasol's coal-to-liquids plants burns cleaner than oil, the production process releases huge amounts of carbon dioxide. The company's Secunda plant is one of the world's largest point sources of carbon emissions. The company thinks carbon capture and sequestration can eventually lessen the environmental impact.

Shell

Shifting focus from oil to natural gas

www.shell.com
Founded: 1907
Management: Peter Voser (CEO), Matthias Bichsel (director of projects and technology), Simon Henry (CFO)
Employees: 101,000
Revenues: $278.2 billion
R&D: $1.2 billion
Market cap: $160.4 billion

Technology: For the past decade, Shell has been one of the major players in extracting gas from nearly impermeable rock. Like other companies, it uses a technique called hydrofracturing, which pushes water and chemicals into the rock at high pressure in order to create a network of cracks that help free the gas. This, combined with the ability to drill horizontally, has allowed it to get at previously inaccessible resources. **Market:** The company, based in the U.K. and the Netherlands, transports oil and liquefied natural gas from its far-flung drilling sites to major markets in Europe, Asia, and North America. **Strategy:** Shell is now focusing on gas exploration and production, and it expects that by 2012 it will produce more natural gas than crude oil for the first time in its history. In May, the company acquired rights to about half a million acres of the Marcellus shale, the vast natural-gas reserve that stretches from New York to West Virginia. **Challenges and next steps:** Although the potential of the Marcellus is huge, the long-term environmental impact of hydrofracturing in the northeastern United States is still unknown. Wells drilled by other companies have been shut down amid environmental concerns, and Shell will have to demonstrate the safety of its techniques.

Total

Expanding markets in Africa

www.total.com
Founded: 1924
Management: Christophe de Margerie (CEO), Manoelle Lepoutre (executive vice president, sustainable development and environment)
Employees: 96,387
Revenues: $157.0 billion
R&D: $910.0 million
Market cap: $120 billion

Technology: Total, based in Paris, is a global producer, refiner, and marketer of oil and natural gas. The company is also starting to branch out into biofuels. Earlier this year it invested an undisclosed amount in Coskata, a startup that makes fuel from a variety of waste materials such as wood chips, grass, and even old tires. It has also invested in battery technology for storing large amounts of electricity from the grid. **Market:** Total is one of the largest petroleum companies in Africa and has a strong position in the productive natural-gas fields off the coast of Nigeria. Although most of that gas is exported to wealthier countries, Total is also active in the growing markets within Africa. **Strategy:** Total has been especially forthright about the eventual end of oil and has diversified into nuclear, solar, and alternative fuels. But it is also well aware that oil and gas will continue to drive economic growth, especially in the developing world, for at least the next few decades. **Challenges and next steps:** Total's extensive holdings in Africa are under constant threat from political and social instability. Earlier this year a Total employee fell victim to one of a long string of kidnappings that have plagued employees of foreign oil companies across the region.

COMPANIES TO WATCH: PRIVATE

Amyris

Engineering microbes for biofuels

www.amyris.com
Founders: Neil Renninger, Jack D. Newman, Kinkead Reiling
Management: John Melo (CEO)
Funding: $244 million in private funding
Key investors: Kleiner Perkins Caufield and Byers, Khosla Ventures, Votorantim Novos Negocios, Advanced Equities

Technology: Employing the principles of synthetic biology, which uses genetic engineering to overhaul an organism's metabolic system, Amyris has designed microbes that process sugar into biofuels and other chemicals. **Market:** The company's first commercial product, farnesene, can be made into a number of chemicals and into industrial and automotive oils and lubricants. Amyris plans to sell the molecule in specialty chemical markets in 2011. Its biodiesel has the same properties as existing diesels and can therefore be sold and distributed using existing infrastructure. **Strategy:** Amyris's first manufacturing plant is in Brazil, the world's most efficient producer of sugar. Using sugarcane instead of more expensive corn sugars as a feedstock for biofuel and chemical production will help keep costs low. The company is working with Brazilian sugar and ethanol producers to make use of existing facilities. **Challenges and next steps:** Amyris still needs to show that it can produce chemicals cheaply and in extremely large volumes. Amyris's first production facility—a joint venture with Usina São Martinho, one of the Brazil's largest ethanol producers—will come online in 2012. Ultimately, the company will need a feedstock that's widely available in the United States.

Coskata

Making ethanol from cellulosic biomass and solid waste

www.coskata.com
Founders: Todd Kimmel, Rathin Datta, Aaron Mandell, Andrew Perlman
Management: William Roe (CEO), Richard Tobey (VP, R&D)
Funding: Not disclosed
Key investors: Total, GM, Khosla Ventures, GreatPoint Ventures

Technology: Biofuels are typically made either in chemical reactions or by fermenting sugars with the help of microbes. Coskata combines the two processes. Materials such as wood chips and old tires are processed under high-temperature, high-pressure conditions to produce a mixture of hydrogen and carbon monoxide known as synthesis gas. Then microörganisms raised in fermentation tanks or proprietary bioreactors developed by Coskata turn the gas into ethanol. **Market:** Coskata's process can easily make fuel from a wide range of raw materials, so it should be marketable in more places than processes tuned for a specific feedstock. **Strategy:** Coskata will license its technology to other companies, such as established biofuel producers. It has developed a modular system with elements that companies can mix and match according to their needs. In April, the company closed a major round of financing, led by French oil giant Total. **Challenges and next steps:** The company has shown that its technology works at a demonstration plant but hasn't yet established that the organisms can produce fuels efficiently and inexpensively on a large scale. Plans for the first commercial-scale plant are being finalized.

GreatPoint Energy

Turning coal into natural gas

www.greatpointenergy.com
Founders: Andrew Perlman, Avi Goldberg, Aaron Mandell
Management: Andrew Perlman (CEO), Donald Anthony (CTO)
Funding: $150 million
Key investors: AES, Dow Chemical, Peabody Energy

Technology: GreatPoint's catalytic hydromethanation technology converts coal (or other feedstocks, including biomass) into natural gas and hydrogen. It also produces pure carbon dioxide. The process occurs in a single step and at a lower temperature than conventional gasification, resulting in higher efficiency and lower costs. **Market:** The natural gas produced through GreatPoint's process can be transported to major markets in pipelines for power generation, home heating, and chemical production. Or it can be converted into hydrogen, which can be used for power generation or sold to refiners or fertilizer manufacturers. The carbon dioxide captured in the process can be used in enhanced oil recovery. **Strategy:** GreatPoint aims to develop large-scale production facilities globally, together with local partners. It is developing these projects near geological formations that are amenable to enhanced oil recovery. Concurrently, GreatPoint will license its technology. **Challenges and next steps:** GreatPoint's success depends on raising enough financing and finding markets with sufficiently high natural-gas prices and cheap feedstocks. It is pursuing sites in China and in North America, and it's evaluating partnerships in India and the Middle East.

LS9

Making renewable hydrocarbons

www.ls9.com
Founders: George Church, Chris Somerville
Management: Bill Haywood (CEO), Stephen del Cardayre (VP)
Funding: $45 million
Key investors: Chevron, Flagship Ventures

Technology: LS9 is engineering microbes to ferment biomass and create a synthetic replacement for diesel fuel. It is developing two processes: one that leads to biodiesel made from fatty esters and another that produces hydrocarbon molecules like those in petroleum-based diesel. The company has isolated naturally occurring genes and enzymes that produce hydrocarbons, transplanted them into *E. coli*, and modified related genes and enzymes to increase their production of fuels. **Market:** LS9 hopes to break into the vast diesel market with a replacement for the petroleum-based products burned in jets, automobiles, and trucks. It also hopes to develop products for the chemical industry. **Strategy:** The company has tested its technology at a pilot plant in South San Francisco and plans to open a demonstration plant in Florida by the end of this year. LS9 is involved in a partnership with Procter and Gamble, which supports the company and uses it as a supplier of chemicals needed to manufacture its consumer products. **Challenges and next steps:** LS9 must secure the funding to build plants, demonstrate the scalability of its technology, and improve the productivity of its organisms to lower the costs of making fuels.

Mascoma

Wood to ethanol in one step

www.mascoma.com
Founders: Lee Lynd, Charles Wyman, Bob Johnsen
Management: William J. Brady (CEO), Michael R. Ladisch (CTO)
Funding: $160 million
Key investors: Marathon Oil, General Motors, Flagship Ventures, Kleiner Perkins Caufield and Byers

Technology: Mascoma is researching efficient ways to commercially produce ethanol derived from cellulose. It is genetically engineering a microbe that, in one step, digests woody biomass to yield sugars and ferments the product into ethanol. This and other advances help decrease the cost of making cellulosic biofuels by reducing the need for the costly enzymes ordinarily used to break down cellulose into sugars. **Market:** As production of ethanol for vehicles increases in accordance with biofuels mandates, Mascoma's new cellulosic-ethanol facility could be a key player in putting wood-based renewables on the market. **Strategy:** Mascoma has a pilot facility in Rome, NY, and is planning a commercial plant in Kinross, MI, which could produce 80 million gallons of the fuel per year. The company is partnering with JM Longyear of Marquette, MI, to form a new company, Frontier Renewable Resources, which will own the Kinross project. Mascoma also expects to collaborate with researchers at Michigan State and Michigan Technological University. **Challenges and next steps:** Like other cellulosic-ethanol companies, Mascoma is still struggling to raise the funding—more than $100 million—required to build its first commercial plant.

COMPANIES TO WATCH: PRIVATE

PetroTel
Information technology for unlocking hard-to-reach oil

www.petrotel.com
Founder: Anil Chopra
Management: Anil Chopra (chairman and CEO), Fred I. Stalkup (VP, enhanced oil recovery), Ram Agarwal (VP, gas engineering)
Funding: Not disclosed
Key investors: Anil Chopra, Marisol Chopra

Technology: PetroTel provides technologies for oil recovery and for oil-field engineering, simulation, and characterization. An affiliate, Plano Research, has developed simulation tools and other software used worldwide by major oil and gas companies. A combination of its technologies, called the "digital oil field," helps companies manage the overwhelming flood of data coming from various oil-field sensing, mapping, and monitoring technologies. The company also collaborates with capital market funds, helping to evaluate financial models of potential resources. **Market:** PetroTel's services support petroleum companies in Southeast Asia, Russia, the Middle East, Africa, and North and South America. These services include helping to devise methods for obtaining hard-to-reach oil locked up in existing oil fields. **Strategy:** The company takes advantage of the fact that the oil industry is being forced to pursue resources that are increasingly hard to find, produce, and recover. **Challenges and next steps:** The petroleum market is volatile and subject to changing government regulations. To protect itself, PetroTel is diversifying through investments in solar and wind technology companies as well as oil and gas companies.

Poet
Making cellulosic ethanol from corn waste

www.poet.com
Founder: Jeff Broin
Management: Jeff Broin (CEO), Mark Stowers (SVP, science and technology)
Funding: Funded by revenue
Key investors: The 27 Poet biorefineries are owned mostly by investors who purchased shares in a private offering.

Technology: In 2006, the company partnered with enzyme maker Novozymes in a project aimed at reducing the cost of enzymes required to break down cellulose. The high cost of these enzymes been one of the major barriers to making cellulosic ethanol cheaply. **Market:** Poet aims to serve the market created by the U.S. Environmental Protection Agency's Renewable Fuel Standard, which requires that 36 billion gallons of renewable fuels be blended into fuel supplies by 2022, almost 50 percent of them from cellulosic sources. **Strategy:** Poet, already one of the largest corn ethanol producer in the United States, is now aiming to become the first commercial-scale producer of cellulosic ethanol. It has an advantage over some competitors because it can start with waste from its conventional ethanol plant. **Challenges and next steps:** The company announced late last year that it could produce cellulosic ethanol at $2.35 per gallon, and it expects to bring the price below $2 per gallon before it breaks ground next year on a commercial-scale plant that will produce upwards of 25 million gallons per year. The company says that even with the federal biofuels mandate, loan guarantees from the Department of Energy could be key to getting the first commercial plants built.

Range Fuels
Wood chips to biofuel

www.rangefuels.com
Founder: Vinod Khosla
Management: David Aldous (CEO), Kevin Biehle (VP, production)
Funding: $156 million in government assistance and over $100 million in series B venture capital
Key investors: Khosla Ventures, Passport Capital

Technology: Range Fuels converts materials such as wood chips and grasses into hydrogen and carbon monoxide gases using a two-step thermochemical process that exposes the feedstocks to high temperatures, high pressures, and steam. Proprietary inorganic catalysts convert the gases into a combination of methanol and ethanol. **Market:** The company has said that in large-scale production it can compete with corn ethanol, currently the cheapest ethanol in the United States. If so, it will gain access to the market for fuel additives, which is already saturated by corn ethanol. If not, it will need to vie with other cellulosic-ethanol producers for new markets. **Strategy:** Range Fuels is producing methanol at its first commercial-scale plant and plans to produce ethanol there this fall. It plans to expand production at that plant from just under 10 million gallons of fuel to 60 million gallons by 2013. It is also evaluating new sites in the southeastern United States. **Challenges and next steps:** Having started commercial production after years of delays that the company attributes to the financial downturn and lack of financing, it now faces the challenge of raising money to fund the plant's expansion.

Rive Technology
Using catalysts to increase fuel yield from oil

www.rivetechnology.com
Founders: Javier García-Martínez, Lawrence Evans
Management: Lawrence Evans (CEO), Larry Dight (SVP, R&D)
Funding: $22.3 million in venture funding
Key investors: Charles River Ventures, Nth Power

Technology: The company has found a way to increase the size of the pores in zeolite catalysts, which oil refineries use in reactions that "crack" long-chain hydrocarbon molecules into smaller fragments that can be used in transportation fuels and other products. By enabling the catalysts to crack larger molecules, the technology allows refiners to obtain more fuel from a barrel of crude oil, make use of cheaper sources, and reduce carbon dioxide emissions. The technology can be added to existing refineries. **Market:** Results from a pilot plant suggest that Rive's catalyst can increase profits by 10 to 15 percent annually at a medium-sized refinery, translating into a potential $15 billion of economic value across the industry. The company is working on applying its technology to other processes, including ones used in biofuel production. **Strategy:** Rive plans to form partnerships with existing catalyst manufacturers and jointly sell their products to refiners. This model will allow it to focus on developing technology and sales while existing suppliers do the manufacturing. **Challenges and next steps:** The technology still needs to be proved in commercial trials, which the company expects to begin later this year. It expects to start selling its product in the second half of 2011.

Solazyme
Fuels from engineered algae

www.solazyme.com
Founders: Jonathan S. Wolfson, Harrison Dillon
Management: Jonathan S. Wolfson (CEO), Harrison Dillon (president and CTO)
Funding: $158 million in venture funding and grants
Key investors: Braemar Energy Ventures, Lightspeed Venture Partners

Technology: Solazyme's process, unlike others that use algae to make biofuels, does not require its microörganisms to be exposed to sunlight. Instead, the algae are kept in the dark inside large fermentation chambers, where they feed on sugars rather than making sugars through photosynthesis. The algae, which can be grown at high density inside such tanks, produce large amounts of oil. This is later purified and then refined into fuel or biochemical products. **Market:** Solazyme has engineered different algae strains to produce different oils, which can be sold to existing oil refineries to create renewable replacements for gasoline, diesel, and jet fuel. The algae can also make oils for products such as cosmetics. **Strategy:** At the same time as it develops its biofuels, the company is courting manufacturers seeking to produce more environmentally friendly versions of cosmetics and nutritional products. **Challenges and next steps:** Solazyme recently received $21.8 million in stimulus funding from the U.S. Department of Energy to build a 300,000-gallon-per-year pilot plant in Pennsylvania. It must deliver on contracts with the U.S. Department of Defense to produce thousands of gallons of jet and ship fuel derived from algae.

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REVIEWS

ENERGY

Cash for Infrastructure

A YEAR AND A HALF AFTER THE FEDERAL STIMULUS BILL BUDGETED $80 BILLION FOR NEW ENERGY TECHNOLOGIES, THE INVESTMENT IS PROVIDING MUCH-NEEDED MOMENTUM FOR CLEAN TECH. BUT WHAT WILL HAPPEN WHEN THE MONEY RUNS OUT?

By DAVID ROTMAN

Scattered across a swath of Michigan that's been devastated by the state's slowdown in automobile manufacturing, a half-dozen or so companies have begun construction on facilities to build advanced batteries for electric vehicles. In the Southwest, two solar thermal plants, each supported by more than a billion dollars in federal loan guarantees, will soon sprawl across thousands of acres in the desert. From Hawaii to northern Maine, ridgelines have begun bristling with wind turbines, made possible in part by government funding.

Enacted 18 months ago, the American Recovery Act is now delivering $80 billion in loan guarantees, tax credits, and cash grants to projects aimed at developing and deploying energy technologies. Speaking in mid-July at a ground-breaking ceremony for an advanced battery factory in Holland, MI, President Obama promised that the plant would be "a boost to the economy of the entire region." But beyond spurring new jobs in clean energy, the Obama administration says, the unprecedented injection of federal money into the energy sector is meant to be a first step in creating "a comprehensive strategy that will pave the way toward a clean energy future for our country." Remaking the nation's energy infrastructure will, of course, take years. But a year and half after passage of the stimulus legislation, it is worth asking whether the strategy is on track. Do the billions of federal dollars being spent on energy research and commercialization really represent the beginning of a comprehensive plan for a clean-energy future? Or are they simply piecemeal investments that will become irrelevant once federal incentives disappear?

AMERICAN RECOVERY AND REINVESTMENT ACT OF 2009

BOULEVARD OF BROKEN DREAMS
Josh Lerner
Princeton University Press, 2009

A BUSINESS PLAN FOR AMERICA'S ENERGY FUTURE
American Energy Innovation Council
June 10, 2010

The U.S. Department of Energy, which alone controls $36.7 billion from the stimulus bill, is now spending from $800 million to $1 billion of that money every month on R&D and the commercialization of new energy projects, according to Steve Isakowitz, the agency's chief financial officer. In a recent interview, Isakowitz said it has been a "huge challenge" to spend the money quickly and efficiently. Some programs have been expanded significantly: spending on modernization of the electric grid, for example, soared from less than $200 million to $4 billion. In other cases, the DOE had to fund entirely new programs. The agency spent $350 million, for instance, to start up the Advanced Research Project Agency–Energy (ARPA-E), which backs high-risk research projects. Despite the challenges, he expects the stimulus-related spending to reach $14 billion in 2011 before dropping off to $9 billion in 2012.

Though President Obama and other supporters of the legislation justified much of the spending as a way to create "green jobs" and thus stimulate the economy, many economists dismiss that idea. Even those who strongly support government investment in technology point out that any spending on research and new energy sources will take years to produce economic growth. Daron Acemoglu, an economist at MIT and a leading authority on the link between economic productivity and innovation, says that while he strongly favors increased federal support for energy innovation on the grounds that we need new technologies to forestall climate change, it is "a joke and totally misguided" to think it will help solve the nation's unemployment problem.

The real value of the stimulus spending has always been in its potential to compensate for years of declining investment in energy R&D and to jump-start commercial use of cleaner energy technologies despite that long decline. The United States spends shockingly little on energy research. In that context, the stimulus bill provided a much-needed boost by allocating $3 billion for energy R&D, including the creation of ARPA-E and a series of research centers around the country. But by far the largest

CHANGING LANDSCAPE Construction is under way in Holland, MI, on a factory to make advanced batteries for electric cars. It is just one of many energy-related projects made possible by funding from last year's stimulus bill.

ADAM BIRD/REDUX

energy expenditures in the stimulus bill support the demonstration and commercialization of new technologies. Loan guarantees, tax credits, and cash grants will supply tens of billions of dollars to advanced battery factories, solar power plants, and biofuel refineries *(see "Taking Stock of the Stimulus," p. 28)*—large speculative projects for which tight credit and depressed financial markets would have made private funding nearly impossible.

These are fragile gains, however. The benefit of increased R&D spending will depend on whether future funding levels remain high or suddenly drop again. Likewise, the fate of the new commercial projects will depend on what happens when federal funding winds down; many of the projects will not, at least in the short term, thrive without various government incentives. For the federal spending to have a lasting impact, the stimulus bill will have to be followed by a practical plan for energy innovation and investment. And as budget hawks in Washington begin to tear apart federal expenditures, any sustainable energy policy will need to justify its government funding in terms of direct, clearly recognizable benefits.

NO DATA

One challenge in designing a practical plan for energy innovation—and convincing politicians and the public of its value—is that no one really knows how to quantify the economic benefits of scientific research. Over the last several decades, economists have convincingly documented how innovation can increase productivity and, thus, economic growth. But little is known about how research leads to innovation or what kind of research is most effective. "The link between R&D and economic impact just doesn't exist on the micro level," says Julia Lane, director of the Science of Science and Innovation Policy program at the National Science Foundation. Lane and colleagues at the National Institutes of Health have begun to study the impact of the research spending called for in the stimulus bill. Initially, the group will simply track stimulus-funded R&D, collecting data on how different disciplines are funded and how many jobs are created. In a second, more ambitious phase of the project, they will try to find new ways to quantify the economic, scientific, and social effects of the research over time.

Few in the scientific community doubt the value of federal support for research, but politicians are not so united. Lane says that if scientists can't demonstrate the impact of their research more clearly, the funding will be in jeopardy. "We ought to be able to have some sense of what investments [in R&D] to make," she says. It's hard to make such policy decisions now, she adds, because "the data on how scientific ideas are created, transmitted, and adopted are limited."

There is, however, plenty of evidence that government funding and policy decisions can, if done correctly, create an environment conducive to innovation. But as Harvard Business School professor Josh Lerner suggests in his recent book *Boulevard of Broken Dreams: Why Public Efforts to Boost Entrepreneurship and Venture Capital Have Failed—and What to Do About It*, government efforts to promote new businesses have a decidedly mixed record. There have been great successes—Lerner describes, for example, the critical role that government involvement played in the early days of Silicon Valley—and dismal failures, such as a program by the Malaysian government to establish a biotechnology zone in what is now known as "the valley of bio-ghosts."

Lerner's book doesn't directly address energy innovation, but the author shows

how important venture capital and entrepreneurship are in realizing the potential of new technologies—and he makes a convincing case that government can encourage these activities.

In a recent interview, Lerner said it is too early to grade the success of the energy spending in the stimulus bill, but he worries that the U.S. government has repeated the mistakes of others. In particular, he says, by making large investments in a relatively few companies, federal agencies such as the DOE have effectively picked winners. A better approach, he suggests, might have been to distribute smaller amounts to more companies and "listen to the market" by linking the government investment to such factors as how much private investment a startup has raised. Regardless of such concerns, though, Lerner stresses that government support for new technologies is crucial. "The government certainly has a role to play in both financing and creating an environment that is conducive to energy-related entrepreneurial activity," he says. "But it needs to be done right."

BIG BUCKS

Over the last several years, a plethora of books, academic papers, and expert reports have proposed ways to formulate a coherent strategy for energy innovation. Notably, in June the American Energy Innovation Council (AEIC), a Washington-based group of industry executives, issued a "business plan for America's energy future," signed by, among others, Microsoft chairman Bill Gates, GE CEO Jeffrey Immelt, and Xerox CEO Ursula Burns. The report calls for tripling annual federal support of what it terms research, development, and deployment (RD&D), from the current $5 billion to $16 billion, of which $1 billion would go to ARPA-E. The business leaders also call for a "national energy strategy board" that should be "external to the U.S. government" and would be charged with supervising an "independent corporation outside of the federal government" that would help commercialize new energy projects. In their plan, this corporation would receive $20 billion over 10 years through a single federal appropriation.

It's to the business leaders' credit that they recognize the importance of government support for energy innovation and the need for "a national energy strategy." Nonetheless, this is politically volatile stuff. The American public, and many politicians, are likely to have little appetite for the prospect of quasi-public corporations or "expert boards" running the nation's energy policy.

Meanwhile, any comprehensive plan for energy innovation will need to deal with a simple technology fact: most existing alternatives to fossil fuels are currently too expensive to replace them to any significant degree. And yet the transition to lower-carbon fuels must begin immediately if the direst effects of global warming are to be avoided. Many economists favor carbon pricing, in the form of a direct carbon tax or a cap-and-trade system; either would effectively force companies to pay for carbon pollution, raising the cost of fossil fuels and making alternatives more competitive. But even some of the strongest advocates of carbon pricing acknowledge that, as Harvard economist Robert Stavins said in a recent interview, it is "essential but not sufficient." In other words, we'll still need energy innovation.

Of course, an "energy miracle" is always possible *(see Q&A, p. 30)*, but to count on a radical breakthrough is to ignore the immediacy of global warming—and the amount of time it takes to fully commercialize energy technologies. A technology that's still in a researcher's lab or on a venture capitalist's whiteboard is at least a few decades from making a major impact on climate change. If the climate scientists are right, any such solution will be too little, too late.

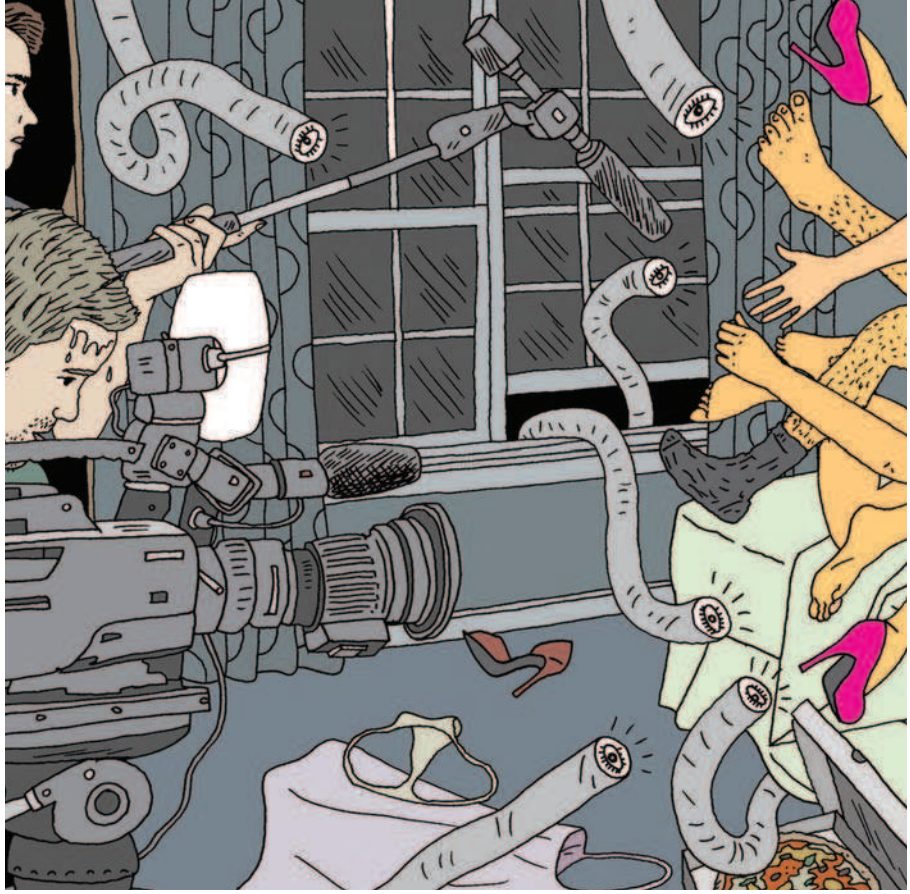
To reduce carbon dioxide emissions during the coming decades, "it's all about large-scale deployment of low-carbon technologies," says Richard Lester, the founding director of MIT's Industrial Performance Center and head of its nuclear science and engineering department, who has spent the last several years on a project to design a more effective energy innovation system. The problem, he says, is that "those technologies today are too costly."

One of the central questions in formulating an effective innovation strategy, Lester says, is how to "bridge the cost gap" between cheap fossil fuels and more expensive low-carbon energy sources. "Our conclusion is that there is no possibility of financing this cost gap in the early stage of deployment of these new technologies with the traditional federal budget appropriations process," he says. "It is just too expensive." Lester adds, "It really makes sense for the users to pay for it. That will be very unpopular, but I don't see any way to proceed otherwise."

The good news is that innovation can bring down the cost of new energy technologies. One of the virtues of the stimulus bill is that it allocates money both to energy research and to deployment; its most creative programs, such as ARPA-E, attempt to combine those objectives. But the success of these investments will be determined by whether they actually turn out to be the initial stages of a comprehensive energy plan. Formulating such a plan will mean studying the growing body of academic research on the most effective ways to encourage innovation. It will mean making some unpopular choices, and it will be expensive.

A year and a half after the stimulus funding began, the mood in Washington has turned frugal. The DOE's proposed budget for 2011 does request increases for energy R&D, but there's little talk of spending additional tens of billions of dollars to support the demonstration of new energy technologies. Without such investments, the projects that got their start with stimulus funding could languish. Rather than laying the foundation for a new energy infrastructure, they will continue to represent mere possibilities for clean technology. TR

DAVID ROTMAN IS *TECHNOLOGY REVIEW*'S EDITOR.



PETER ARKLE

INTERNET

Down the Tubes

HOW FREE STREAMING VIDEO THREATENS THE PORN INDUSTRY.

By SCOTT FAYNER

Editor's note: *The following review is about pornography. If the subject itself offends, please stop reading. Why write about it? First, because pornography is "intimately linked with the evolution of communications technology," as one history professor interviewed puts it. Second, because the porn industry, like the music and newspaper industries, faces a technological problem and doesn't know what to do next.*

I was 29 and had been living in Los Angeles for nine months when I took a job with Larry Flynt Publications. Technology was the last thing on my mind, but that would change quickly. The most famous of the 20 magazines under the roof was *Hustler*, the raunchiest of the three big American skin mags. But within a year of my arrival, in 2000, some of the less popular titles folded, and it was clear that a shift was in the air.

The shift worked to my benefit—my bosses created an online division and put me in charge of its editorial side. From that perch I saw firsthand how changing technologies both benefited and wounded the mighty porn machine. When I joined Flynt, it produced 20 magazines and four websites; today, it produces a handful of magazines and dozens of websites. Smaller companies gained power, since it was cheaper to put material online than to package and distribute magazines, tapes, or DVDs. And in the most wide-reaching development, high-speed Internet has spawned something called tube sites—file-hosting sites that offer rivers of free streaming video. These sites threaten to undo porn as we've known it.

WWW.PORNHUB.COM
WWW.XVIDEOS.COM
WWW.YOUPORN.COM

The troubles for the porn studios began with a technology called BitTorrent, introduced in 2001, which made it easy for people to share data files over the Internet. This technology provided the world with unlimited free music, much to the dismay of the giant music publishers. But it was still somewhat clunky. If you wanted to watch a video, you had to download it, which took time and ate up space on your hard drive.

By 2005, the BitTorrent technology gave way to something more manageable and user-friendly: streaming video. This technology was used early and heavily by sites with names like PornHub, Xvideos, and YouPorn. Suddenly, anybody who wanted to watch a clip could do so almost instantly. You clicked on a video and it played in the browser: no more waiting, no more downloading.

This simple innovation has demolished the porn industry's traditional way of doing business. Porn tube sites are now among the most visited websites in the world. According to the online measurement company Alexa, PornHub holds a worldwide traffic rank of 54. Xvideos is at number 53, and YouPorn is at number 64. The threat comes from the sheer ease of uploading content—anyone's content—onto a site and then drawing users to view it. Most tubes describe themselves as aggregators of "user-generated content," but the material they publish is much broader—many video clips are created, paid for, and owned by porn studios.

"Piracy has hurt us a lot," says Ali Joone, founder and director of the adult-film company Digital Playground, which last year tracked illegal downloads of its most popular title, *Pirates*. "Over the course of a month, it was downloaded about four million times. And that's just from a handful of sites. Even if those downloads cost us a thousand customers, let's say, who were going to pay—that hurts."

The porn studios face the same fundamental question as any content provider in the Internet age: how do you protect your stuff once it's "out there"? The answer, so far, is, "Not well."

The tube effect has been profound enough to inspire a recent public-service announcement featuring more than a dozen adult per-

formers and directors pleading with fans not to view pirated porn. One actress, Charley Chase (who did not participate in the PSA but says she faces the same troubles), got into the business in late 2007 on the promise of lots of work at high pay. But the pay has dropped and the work has dried up. "And it's all because of piracy," she says.

According to Travis Nestor, a former agent for and a founder of the now-defunct It Models, a scene that might have paid an actress $900 in 2004 will now net her $600. In the same period, rates for male performers have dropped from around $500 per scene to $300. But that's only half the effect, because there are fewer studios making fewer movies. Joone says that five years ago the industry might have released 400 new titles a week, but that output has been cut in half. "People just aren't buying," he says.

"EVEN WITHOUT PORN, WE'D PROBABLY ALL HAVE HIGH-SPEED INTERNET, BUT IT WOULD HAVE BEEN ADOPTED MORE SLOWLY, IN THE SAME WAY THAT THE SPREAD OF THE VCR WOULD HAVE BEEN DELAYED IF PORN WEREN'T AROUND, BECAUSE THE EARLY ADOPTERS WOULDN'T BE THERE."

It's difficult even for people in the industry to get a sense of how many studios have closed, partly because the porn business—unlike, say, the music business—does not consist of large conglomerates. Instead, it's made up of shifting constellations of modest-sized companies. Diane Duke, executive director of the Free Speech Coalition, a trade association for the adult entertainment industry, says the number of studios is still in the thousands (representing everything from big production houses to "mom-and-pop shops"), but it's dropping. "Our industry is woefully lacking in stats," she says. "Everybody keeps their numbers tight to their chest. But we've definitely seen the decline."

The tube sites, meanwhile, find shelter in the Digital Millennium Copyright Act, a U.S. law passed in 1998. The act says that websites aren't responsible for any copyrighted material that shows up on their pages unless somebody points it out to them. "But that only protects them up to the point that they receive a cease-and-desist letter from us," says Joone. "Then they have to take it down. If they don't take it down, then that's copyright infringement."

For the tube operators, the risks have been worth it. "Most of the time, the tube sites are just two or three people," Joone says. "They haven't paid for the content. The only expense they have is bandwidth, and then they have advertisers paying them a lot of money for the traffic they're creating." Joone says a typical tube site might pull in several hundred thousand dollars every month.

One defense against the tube sites is "spider" technology. Spiders, or Web crawlers, are employed by search engines to index site pages. In the porn world, a spider could find stolen content hiding anywhere in cyberspace. But it's an exhausting effort, and the results are weak at best. "Even with spiders, we aren't winning," says Los Angeles–based adult-film director Jonni Darkko. "Most of the tube sites are run out of foreign countries, so there's not much we can do to them. Plus, if they receive an order to remove a pirated scene, instead of taking it down, what they'll do is just change the title and put it somewhere else on the page."

There have been a few lawsuits for copyright infringement in the porn world. In April, adult actress Vicky Vette filed a lawsuit against the file-hosting site RapidShare for allowing her content to be given away. Vette told me she has no idea if she can win but felt she needed to draw a line in the sand. "We have to try and stand up now," she says, "or an entire generation of surfers is going to think it is ridiculous to pay for anything."

Joone acknowledges that it's been a bit of a "cat-and-mouse game." But he says the tube sites are a technology problem with a technological solution—in this case, something called digital fingerprinting. "We've been using it for the last two months, and we've targeted about 10 tube sites with it," he says. The technology essentially "ingests" a film, Joone says: "Be it one frame, be it 10 minutes—it can find it, and what it does then is send an automatic cease-and-desist takedown notice. And then it checks back every two hours to make sure it's been taken down. And it will log that clip for legal purposes." He's confident that this technology will provide enough evidence to make lawsuits effective where they haven't been in the past. "We do have a consortium of adult producers that right now, behind the scenes, are taking a tube site to court," he says.

All this back-and-forth between the porn studios and the tube sites is just the latest episode in a relationship between porn and technology that goes back at least to the printing press. And the rise of the tubes is hardly the first time technology has overturned pornography's established modes of business. The Polaroid camera, the VCR, pay-per-view, 900 numbers, live chat, video chat, and high-speed broadband all got early exposure as porn delivery systems. As a result, porn has been normalizing the use of new technologies for a long time.

"Things like the book or the motion picture weren't invented with the idea of 'Oh, let's make pornography with this,'" says Jonathan Coopersmith, a history professor at Texas A&M who has studied the porn industry for more than a decade. But porn "quickly becomes a tool for diffusing knowledge of how these new things work, and it creates an early market," he says. "Even without porn, we'd probably all have high-speed Internet, but it would have been adopted more slowly, in the same way that the spread of the VCR would have been delayed if porn

weren't around, because the early adopters wouldn't be there."

Diane Duke thinks the tube sites and the porn studios will ultimately learn to work together, because it's in both their interests. The tube sites won't want to deal with lawsuits, and the studios won't be able to say no to all those additional page views. Duke envisions a system in which a clip on a tube site would link to a pay site, allowing viewers to buy more scenes or the whole movie. The tube site would get a cut of any purchase.

Duke says people focus on the fact that the tube sites are free, but they've got another advantage—they make it quick and easy for people to access clips. She says the porn studios must create a pay model that doesn't make the customer feel it's a hassle to hand over a few dollars in exchange for a scene and that allows the source of the charge to be disguised. She imagines something like iTunes, with movies broken into chunks sold like individual songs.

If these options don't work, there's always another: some porn producers are buying up tube sites themselves. Other producers are building new tubes, giving away quick clips of their own movies in the hope that advertising revenues and site memberships (offering higher quality and full-length clips) will make up for their losses in the DVD market.

Joone says the companies that thrive will find a way to offer something that people think is worth paying for. Digital Playground, he believes, has survived in part because it caters to the couples market. Such customers, he says, want decent production values and at least some kind of story; they're much less likely to be satisfied by a series of disjointed clips on a tube site. But he also acknowledges that the tubes aren't going anywhere anytime soon.

"If you just want something to look at, you can get that for free," he says. "You can get that from now until the end of your life." TR

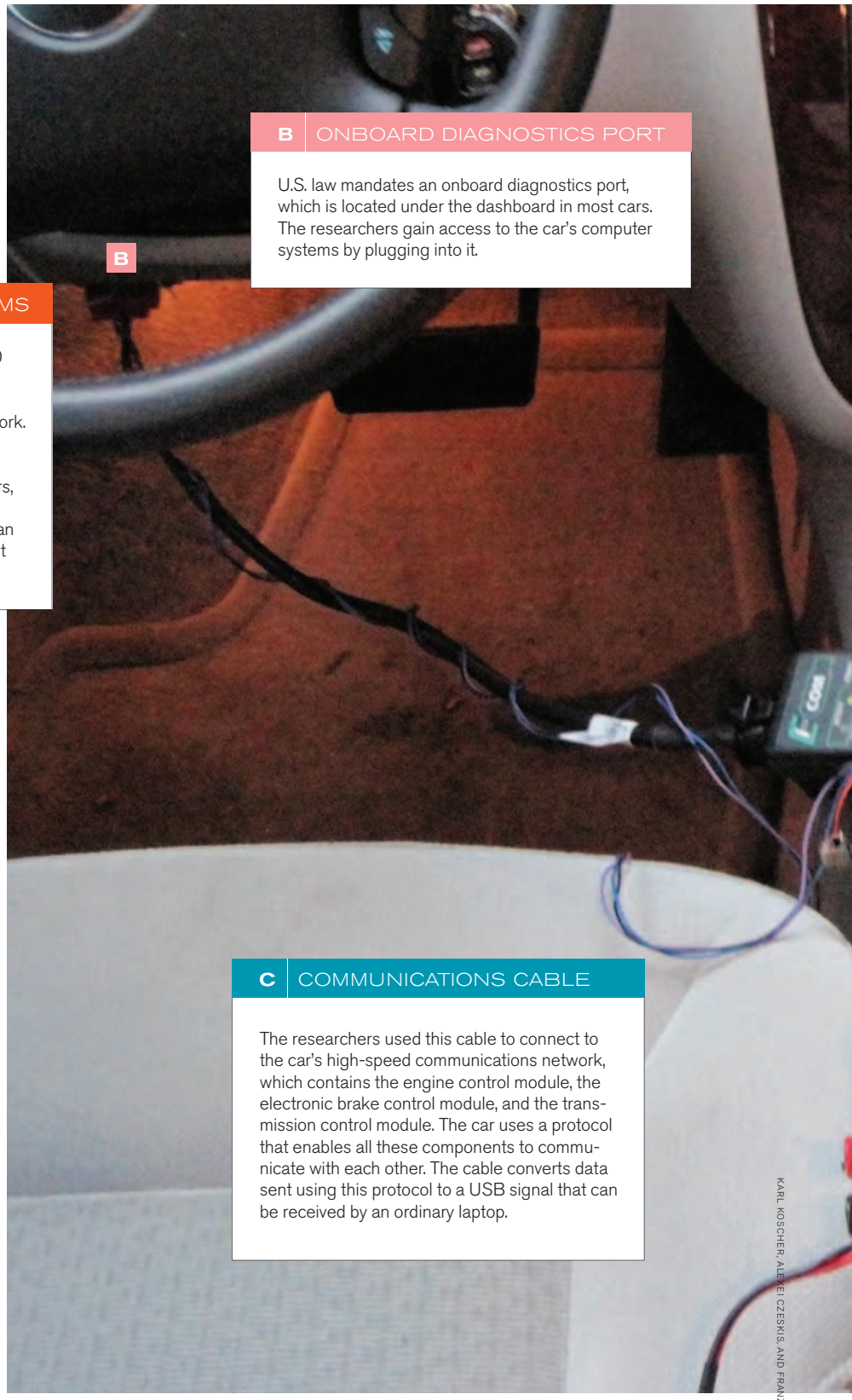
SCOTT FAYNER RAN THE POPULAR GOSSIP SITE LUKEFORD.COM, COVERING THE PORN INDUSTRY. TODAY HE PUBLISHES A MONTHLY ONLINE MAGAZINE DEDICATED TO BOSTON DOGS, CALLED MASSARF.

Taking Over a Car

RESEARCHERS "BREAK IN" WITH SOFTWARE AND A LAPTOP

By ERICA NAONE

CARS ARE BECOMING more computerized, an evolution that could have an unintended side effect: vulnerability to attacks. Researchers at the University of Washington and the University of California, San Diego, led by Tadayoshi Kohno and Stefan Savage, recently showed that by taking over a car's computers, they could disable the brakes, stop the engine, and control the door locks. For now, most of the attacks require access to a port inside the car. But wreaking havoc could get easier as carmakers add more wireless connectivity. The researchers hope their work will motivate manufacturers to add security features.



A COMPUTERIZED SYSTEMS

A typical luxury sedan contains 50 to 100 computers controlled by over 100 megabytes of code. Most of these computers communicate over a shared internal network. These systems have surprising interconnections that attackers could exploit, the researchers say. For example, in many cars, the door locking system and the crash detection system are linked. That means an attacker who takes over the locks may get access to key internal systems.

B ONBOARD DIAGNOSTICS PORT

U.S. law mandates an onboard diagnostics port, which is located under the dashboard in most cars. The researchers gain access to the car's computer systems by plugging into it.

C COMMUNICATIONS CABLE

The researchers used this cable to connect to the car's high-speed communications network, which contains the engine control module, the electronic brake control module, and the transmission control module. The car uses a protocol that enables all these components to communicate with each other. The cable converts data sent using this protocol to a USB signal that can be received by an ordinary laptop.

KARL KOSCHER, ALEXEI CZESKIS, AND FRANZI ROESNER

D CUSTOM-BUILT CONNECTION

A low-speed network connects less critical parts of the car's computer system, such as the air conditioning, the radio, and the theft deterrent module, which prevents the car from starting without a legitimate key. The researchers loaded their own code onto a circuit board, which was then able to translate between the laptop and the car's systems.

E CARSHARK INTERFACE

The researchers developed a custom "CarShark" interface—which can run on an ordinary laptop—to track and control the messages that various computer systems send each other over the car's networks. They executed their attacks through this interface, and in some cases they sent it wireless commands from a nearby car.

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How to Remake Life

VENTER INSTITUTE RESEARCHERS HAVE MADE THE FIRST VIABLE CELL WITH A SYNTHETIC GENOME.

By KATHERINE BOURZAC

With a precise motion, Li Ma, a technician at the J. Craig Venter Institute in Rockville, MD, pipettes a cherry-red solution of bacterial cells into a vial that contains a clear solution of fragile DNA loops. These loops, the largest pieces of DNA ever assembled in the lab, are each capable of controlling all the ordinary functions of a cell. But the DNA didn't originate in any bacteria: instead, scientists pieced it together from bottled chemicals. The process they recently developed for doing this is the first to yield synthetic cells that are capable of surviving. Some of the bacterial cells that Ma is working with will fuse together in the solution, engulfing the synthetic genome and then replicating and living under its control.

Conventional genetic engineering is a lengthy process in which genes are altered one by one, often over successive generations of organisms. That makes radically changing a genome a daunting proposition. But the newly developed techniques allow researchers to edit genomes on a computer, subtracting or adding genes by literally cutting and pasting them in a file. It's more like word processing than the traditional lab work involved in culturing and screening generations of organisms. The researchers can then perform the genetic equivalent of printing out the file, at which point they're able to transplant the result—a new genome—into existing cells. These steps dramatically speed up the engineering process; it might take just weeks to complete experiments that previously would have taken months or years.

Ultimately, researchers want to use synthetic biology to design microbes that very efficiently produce vaccines, clean fuels, and other products. But they can't engineer new genomes from scratch, because they don't yet know enough about what genes and networks of genes are needed to sustain life and produce a desired product. "You might remove one gene and the cell lives; remove a second and it dies; then remove a third and it lives again," says Daniel Gibson, an associate professor at the institute. Thus, the Venter researchers are experimenting with the sequence of a naturally occurring genome. They hope to learn more about how genomes and cells work by rapidly deleting and adding genes in different combinations, incorporating the new genomes into cells, and then observing how those genomes function or fail to function.

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1. A modified version of the gene sequence for the bacterium *M. mycoides* is shown here on a computer display. Researchers have deleted genes and added watermark sequences. They use software to divide the sequence into 1,100 pieces.
2. This stack of containers stores fragments of synthesized DNA that, when joined together, will form the entire bacterial genome. Each container has multiple wells, each of which contains copies of one section of the genome.
3. Researcher Daniel Gibson combines a mixture of 10 consecutive DNA fragments with yeast cells that will stitch them together in the correct order, forming a circle of DNA. The stitching process is repeated until the yeast have assembled the complete genome.
4. Multiple yeast colonies bearing synthetic DNA are smeared on petri dishes that are numbered to identify which part of the synthetic genome they carry.

RYAN DONNELL

GENETIC REVISION

The process starts on the computer, where Gibson pulls up the genome of the bacterium *Mycoplasma mycoides*. It's a relatively simple one, comprising just 1,078,809 DNA base pairs that make up about 900 genes. (In comparison, *E. coli* bacteria have about 4,400 genes.) Gibson and his colleagues have made a few changes: they've deleted 14 genes from the sequence and added others. To create a watermark distinguishing their creation, they developed a code that converts English into the four-letter alphabet of DNA and used it to modify the genome, incorporating their names, a URL, a few sentences, and an e-mail address into the genome.

Gibson's group then uses software to divide the modified genome into 1,100 sections, each about 1,080 base pairs long—a size that can be made economically with a DNA synthesizer, a machine that pieces together stretches of DNA from individual base pairs supplied in bottled solutions. Finally, the researchers enlist yeast cells to stitch these long sections together, a job that machines can't do.

Gibson kneels in front of a refrigerator in the lab and pulls out 12 plastic boxes, each of which contains 96 wells full of DNA fragments based on the computer-modified designs. He stacks them on a bench and says, "This is the entire genome in 1,100 pieces." Gibson uses a pipette to gather 10 fragments in order and adds them to a tiny plastic tube, along with an additional fragment of DNA that will help pull the sequence together into a loop. Next he adds yeast cells that have been treated to allow them to take up the DNA pieces. "Each yeast cell thinks these pieces of DNA are part of its own chromosome, and it's broken," he says. "It wants to put them back together." The researchers designed the DNA fragments so that the ones to be linked together have ends with matching sequences. The yeast pieces the 10 fragments together by matching these sequences to produce DNA loops that are each 10,000 base pairs long. Repeating the process links the 10,000-base-pair sequences to form 100,000-base-pair segments of the genome. After a third pooling step, the yeast have stitched together the entire synthetic genome. Using established methods, the synthetic genomes are extracted from the yeast.

Handling the extracted DNA takes considerable care: even a small genome is a gigantic, fragile molecule. "It's going to break into 100 pieces if you just look at it wrong," Gibson says. If it were suspended in a liquid solution, the DNA could be destroyed merely by the movement of the liquid. So Gibson immobilizes the genomes in agarose, an algae-derived gel commonly used as a medium for microbes. Enclosed in this

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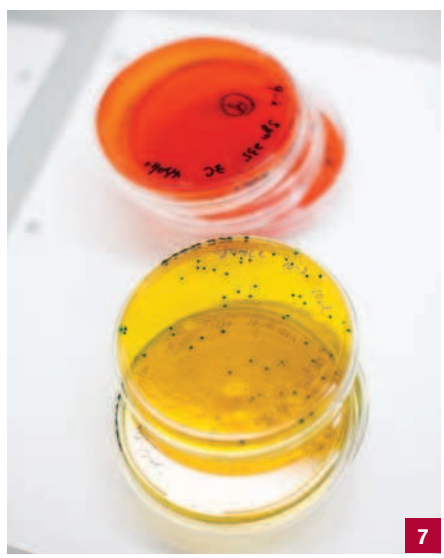

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5. Multiple copies of the completed synthetic genome are encased in agarose gel inside this tube. The gel immobilizes and protects the fragile DNA loops.
6. Researcher Li Ma mixes bacterial cells with copies of the synthetic genome. This must be done gently to avoid breaking the DNA. The mixture sits in an incubator for three hours. The cells have been treated to encourage them to fuse together; as they do, some of them encapsulate a synthetic genome that had been floating in the surrounding solution.
7. A solution of cells, some of which contain the new genome, is mixed with a gel-based culture medium that contains an antibiotic. Then it's poured into petri dishes and put into an incubator. Only cells containing the synthetic genome carry a gene that protects them from the antibiotic. The blue spots are colonies of bacteria now controlled by the transplanted synthetic genome.

protective pellet, they can safely be stored until the researchers are ready to transplant them into recipient cells.

TINY TRANSPLANT

In a lab down the hall, Ma has prepared the cells that will receive the new sequence: a species of bacteria called *Mycoplasma capricolum* that's closely related to the species from which the synthetic genome is derived. While an enzyme that degrades agarose liquefies DNA-containing pellets in one test tube, Ma gets another test tube and mixes the bacteria with calcium chloride and polyethylene glycol, a cocktail that the researchers believe makes the cells' surfaces malleable and sticky. Now it's a matter of chance and a steady hand. Ma pipettes some of the cell mixture into the vial containing the synthetic genome loops. The sticky cells begin fusing with one another. To maintain their spherical shape after fusion, they must take in volume from the solution around them. As this happens, some cells—about one in 100,000—also take in the synthetic genome. The result is a sort of supercell with three genomes—the synthetic genome and one from each of the two cells. The supercell then divides into three smaller cells, one of which contains the synthetic genome.

Ma smears the cell solution on culture plates containing an antibiotic to which only cells with the synthetic genome are resistant (during the genome editing process, the researchers added a gene that makes them impervious to it). Those cells will live, growing and dividing under the control of the new genome. The rest die off, leaving behind a pure colony of synthetic cells.

The next step for the Venter Institute researchers is to use their genomic editing, synthesizing, and transplanting techniques to design and test genomes with fewer and fewer genes. The goal is to create a "minimal" cell—one with only the genes it needs to survive. Such a cell could be easier than a natural one to alter through genetic engineering.

www Watch Venter Institute researchers synthesize a genome: **technologyreview.com/demo**

The researchers' methods are currently very expensive: it costs $300,000 to $500,000 to make and transplant a synthetic genome if the researchers synthesize the DNA in house, or about three times that much if they purchase it from an outside supplier. Yet the price of DNA synthesis is falling and may continue to decline even further as demand increases and technology improves. If that happens and the genome-building techniques prove as useful as the Venter researchers hope they will, more people will begin to adopt their methods, says James Collins, a professor of biomedical engineering at Boston University.

"This is a significant advance for synthetic biology," Collins says. "Now we've got to see, what are the changes that can be introduced to the genome?" TR

RYAN DONNELL

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Professor John J. Renton says that predictions of the inevitable decrease and disappearance of worldwide oil supplies appear all too accurate. On the other hand, he notes, "Coal is to the United States what oil is to Saudi Arabia. We have more coal than anybody in the world." While other options certainly will be pursued, coal seems destined to play an important role in America's energy economy.

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Image courtesy of USGS/Cascades Volcano Observatory.

On May 18, 1980, Mt. St. Helens exploded in the most deadly volcanic eruption in the history of the United States.

Like many geologists, Dr. Renton is plain-spoken, no-nonsense, rugged, and with a tinge of romanticism. He is also an award-winning educator with 40 years of experience teaching introductory geology at West Virginia University. You will find him spontaneous, well-organized, funny, and easy to follow.

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FROM THE LABS

BIOMEDICINE

Growing New Livers

SCAFFOLD FROM DAMAGED ORGANS MAY PROVIDE THE BASIS FOR NEW ONES

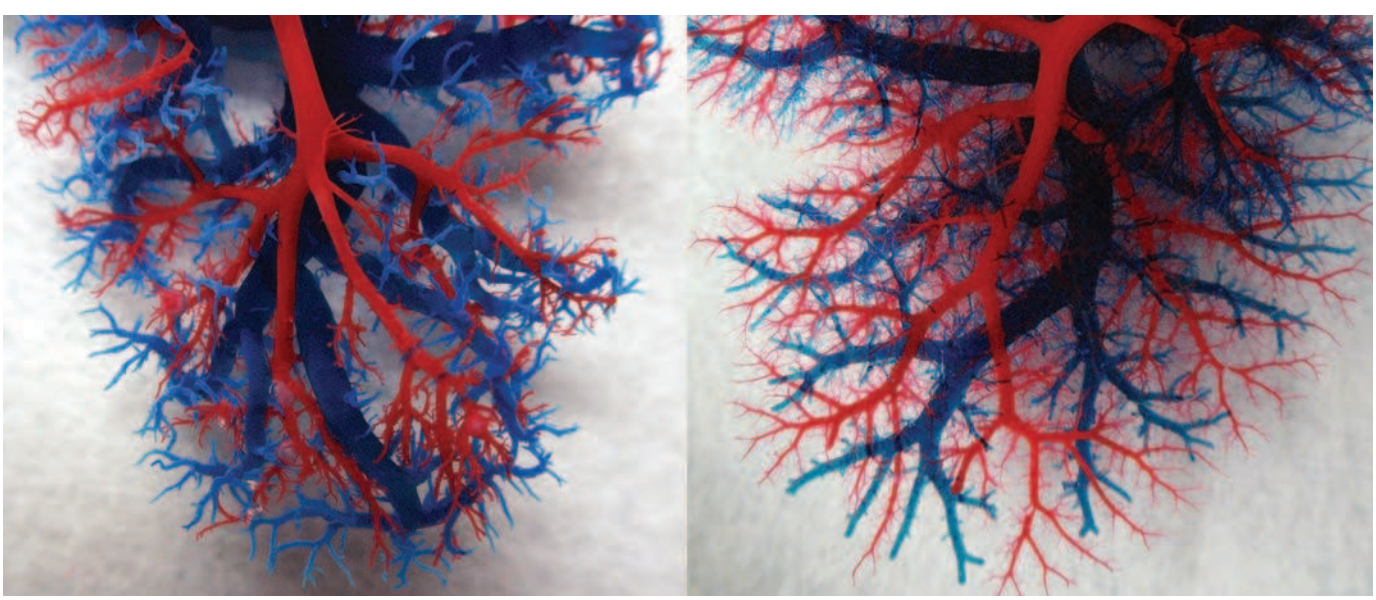
SOURCE: "ORGAN REENGINEERING THROUGH DEVELOPMENT OF A TRANSPLANTABLE RECELLULARIZED LIVER GRAFT USING DECELLULARIZED LIVER MATRIX"
Basak Uygun et al.
Nature Medicine 16: 814–820

Results: Researchers at Massachusetts General Hospital, in Boston, grew new livers by removing the cells from an existing rat liver and seeding the scaffold left behind with healthy liver cells. The new organs were able to function for a short time when transplanted into rats.

Why it matters: Not enough donor livers are available for everyone who needs one, and the organ's complex three-dimensional structure has made generating replacements very difficult. The research could one day provide a way to use unhealthy organs to grow healthy ones.

Methods: Scientists used a detergent to remove cells from the existing liver, leaving a scaffold of proteins and other molecules. The basic architecture of the liver's complex network of blood vessels remained intact. To the empty scaffold, the researchers added a mixture of liver cells and endothelial cells, the cells that line blood vessels. The cells grew into an almost complete organ that functioned for 10 days in a dish and for up to eight hours in live animals.

Next steps: The researchers plan to transplant the organs into rats for longer periods to see if they might function well enough to replace a damaged liver. This will require adding more endothelial cells, because the current reconstructed livers don't have enough blood vessels to work properly for long. The team is also experimenting with using stem cells rather than liver cells to populate the scaffold, which could potentially enable patients to use their own cells.



LIVER SCAFFOLD The network of blood vessels in a decellularized liver (left) looks the same as that in a normal one (right).

B.E. UYGUN AND O.B. USTA

Cheap Blood Typing

A 10-CENT PAPER TEST COULD IMPROVE MEDICAL CARE IN POOR COUNTRIES

SOURCE: "PAPER DIAGNOSTIC FOR INSTANTANEOUS BLOOD TYPING"
Gil Garnier et al.
Analytical Chemistry 82(10): 4158–4164

Results: Researchers made a blood-typing test from a piece of paper treated with antibodies. It can determine an individual's blood type as accurately as more complex existing methods.

Why it matters: Blood transfusions can cause a potentially fatal reaction if the recipient's and donor's blood types conflict. Current methods of determining blood type require costly machinery, which is often difficult to obtain or maintain in poor countries. The new test costs about 10 cents to make.

Methods: Using an ink-jet printer, researchers printed a

a pattern of channels on paper with hydrophobic ink. Then they used the printer to deposit antibodies designed to bind to specific molecules associated with the different blood types. On each of three tabs extending from the center of a piece of paper, they printed a different antibody within the channels. Blood dropped into the center diffuses along the tabs and stops when it encounters the antibody that matches the molecule characteristic of its type. Scientists read the results by assessing how far the blood has traveled down the tabs.

Next steps: The researchers are now looking for industrial partners to bring the diagnostic to market.

INFORMATION TECHNOLOGY

Car Hacking

COMPUTER SYSTEMS IN MODERN AUTOS CAN POSE A SECURITY RISK

SOURCE: "EXPERIMENTAL SECURITY ANALYSIS OF A MODERN AUTOMOBILE"
Karl Koscher et al.
IEEE Symposium on Security and Privacy, May 16–19, 2010, Oakland, CA

Results: A group of researchers at the University of Washington and the University of California, San Diego, have demonstrated that it's possible to take unauthorized control of a car's embedded computer systems. After gaining access through the federally mandated onboard diagnostics port—located under the dashboard in almost all cars today—they could disable a vehicle's brakes, stop its engine, or take control of its door locks, among other things.

Why it matters: A typical luxury sedan now includes 50 to 70 embedded computers controlled by about 100 megabytes of code. The researchers wanted to demonstrate the need for added security at a time when more of these computer systems are gaining wireless capabilities. For the most part, however, the hacks they've performed so far required physical access to the car. The possibility of interfering with a car's computer remotely is a concern mainly for future models.

Methods: Without any special knowledge from the manufacturer, the researchers pulled the hardware from a car and ran standard security analyses such as fuzzing, which tests software to see if it's possible to induce any glitches or strange behavior. They used this information to craft attacks that could take over and control systems on the car's internal network. They tried out their attacks on a parked car and then in road tests to ensure that they were practical in the real world.

Next steps: Many of the techniques commonly used to protect electronic devices won't transfer well to cars: a corrupted braking system, for example, can't just shut down. The researchers hope to work with manufacturers to develop more appropriate security features.

EASIER 3-D A new display directs different patterns of light to each eye to create a 3-D image.

MICROSOFT

3-D Without Glasses

A NEW KIND OF DISPLAY CAN DELIVER 3-D IMAGES DIRECTLY TO MULTIPLE USERS

SOURCE: "BACKLIGHT FOR VIEW-SEQUENTIAL AUTOSTEREO 3D"
Adrian Travis et al.
Society for Information Display 2010 Digest, 215–217

Results: Researchers at Microsoft created a thin TV display that can show a 3-D image simultaneously to two viewers, who don't need to wear special glasses. The display can also send each of the viewers a different image.

Why it matters: Researchers and companies have been trying to develop 3-D displays that are more realistic, comfortable, and practical than the current technologies, most of which require cumbersome or expensive eyewear. Better ways to deliver 3-D images could lead to new consumer devices and more realistic teleconferencing.

Methods: The Microsoft researchers simplified an existing method of directing light to a particular viewer. The display is made of a plastic wedge with a liquid-crystal display screen in

front of it. A camera on top of the display tracks each viewer's gaze. Depending on where the viewer is looking, 30 light-emitting diodes in a row along the bottom of the display switch on and off to direct light into the wedge, which in turn directs it out of the LCD screen and toward a particular eye. The system can quickly send out light signals representing as many as four images. The images arriving at each of a viewer's eyes differ slightly, making the video appear three-dimensional.

Next steps: The group is looking at other ways to use the display. If integrated into the backlight of a laptop screen, it could provide a way to toggle instantly between a private view, in which the backlight steers the images toward a single person's eyes, and a shared view, in which the images shine out in all directions.

MATERIALS

Artificial Antibodies

A POLYMER BINDS TO TOXINS IN THE BLOOD

SOURCE: "RECOGNITION, NEUTRALIZATION, AND CLEARANCE OF TARGET PEPTIDES IN THE BLOODSTREAM OF LIVING MICE BY MOLECULARLY IMPRINTED POLYMER NANOPARTICLES: A PLASTIC ANTIBODY"
Yu Hoshino et al.
Journal of the American Chemical Society 132: 6644–6645

Results: Studies in mice provide the first evidence that a lab-made antibody designed to bind to the bee-sting toxin melittin behaves like a natural antibody in animals.

Why it matters: Antibodies—proteins that bind tightly to specific targets—are widely used in diagnostics such as HIV tests and in treatments for cancer and other diseases. But they're fragile and must be produced by living organisms, an expensive process. Stable artificial polymers that bind to specific molecules could bring down the price of medical diagnostics and broaden access to antibody therapies.

Methods: The researchers made a polymer with a high affinity for melittin by mixing the toxin with the polymer's building blocks and triggering chemical reactions that link the building blocks together. The polymer grew around its target so that it was "imprinted" with the molecule's shape. After being purified and tagged with a fluorescent molecule, the polymer was injected into mice that had previously been injected with melittin labeled in a different color. The researchers then used fluorescence imaging to track the molecules' paths in real time. They determined that the artificial antibody bound to melittin in the blood and was then carried to the liver, the same path taken by natural antibodies.

Next steps: The researchers will use the same methods to make "plastic antibodies" that target other toxins more commonly associated with health risks.

Better Batteries

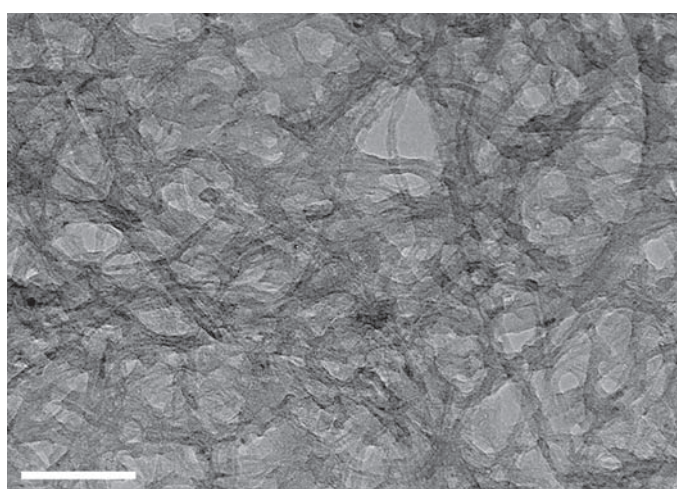
NANOTUBE ELECTRODES DELIVER MORE POWER

SOURCE: "HIGH-POWER LITHIUM BATTERIES FROM FUNCTIONALIZED CARBON-NANOTUBE ELECTRODES"
Yang Shao-Horn et al.
Nature Nanotechnology 5: 531–537

Results: A lithium-ion battery with a positive electrode made of carbon nanotubes delivers 10 times as much power as a conventional battery and can store five times as much energy as a conventional ultracapacitor.

Why it matters: Researchers have been trying to make battery electrodes from carbon nanotubes because they are highly conductive and have a large surface area, two characteristics that are important for power density and storage capacity. Lithium-ion batteries with nanotube electrodes could extend the range of electric vehicles and allow electronic gadgets, including smart phones, to work longer without recharging.

Methods: MIT scientists made dense, porous nanotube films by dipping a glass slide alternately in solutions of positively and negatively charged nanotubes. The films were then heat-treated and incorporated into a lithium-ion battery with a conventional negative electrode and electrolyte. When current was passed through the battery, lithium ions reacted with oxygen on the surface of the nanotubes. The electrodes' porous structure improves energy density by providing a large number of reaction sites for the lithium ions, as well as an easy route in and out of the electrode.



SUPERCHARGED Nanotube electrodes like the one shown here in cross-section could boost battery power.

SEUNG WOO LEE, SHUO CHEN, PAULA HAMMOND, AND YANG SHAO-HORN

Next steps: The researchers are developing a technique for spraying the nanotube solutions on the slide, which should speed up the process of making the films from days to hours. They have licensed the technology to an undisclosed battery company. TR

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Sign of the Times

A YEAR BEFORE THE OIL SHOCK, A GEOLOGIST WROTE OF THE COMING ENERGY CRISES

By MATT MAHONEY

It was with something like an apology that Earl Cook, a geologist and executive secretary of the division of earth sciences at the National Research Council, began his December 1972 article for *Technology Review* on the energy issues that he felt people would face in the next millennium. Geologists tend to take the long view of our existence on this planet, but Cook worried that his readers would fail to see the relevance of his points.

It may seem only a pleasant intellectual excursion without practical significance to attempt to look either back or ahead on a scale of centuries at man's use of energy resources. Given the exigencies of public decision-making, this venture may be just an intellectual excursion and nothing more. But bear with me ... .

He needn't have worried: the following year brought the OPEC embargo, which revealed how utterly dependent we were on access to cheap energy. But of course, the oil shortage caused by the embargo was due to political conflicts, not geology. What motivated Cook was an idea that was then somewhat novel: that we were fast approaching the limit of the fossil fuels we could extract from the earth.

Throughout most of his history as an identifiable species, man relied on renewable energy resources for food, heat, protection from other animals, and to power boats, drive mills, lift water, and pull plows. Only about 150 years ago did he start, on a significant scale, to switch over from wood and wind, from animals and falling water, to heat and power derived from the nonrenewable resources which we call the fossil fuels. In a brief span of little more than a century, industrial-technological man has become utterly dependent on nonrenewable energy resources. Moreover, he has allowed his and the whole world population to expand enormously on the basis of a rate of energy supply that cannot possibly be maintained ... .

Cook was careful not to get ahead of himself, since he knew that his readers would have seen no evidence of this imminent crisis as yet. He also acknowledged that we could defer a crisis by finding ways to get more energy out of the ground or by developing technology, like cars with improved gas mileage, to make better use of it. But he insisted that none of those solutions would be permanent. "We are dependent on nonrenewable resources which have finite quantity limits," he wrote. In other words, one way or another, we were going to run out.

ALL GUZZLED UP The 1973 oil crisis made our dependence on fossil fuels all too apparent.

The big question then and now is: how much time do we have? Cook felt fairly certain that "world crude will not be available beyond about 2025." It turns out not to be as dire as he thought. Oil companies have pushed back the day of reckoning by drilling in remote places (the oil that poured into the Gulf of Mexico from a well nearly a mile below the surface offers testimony of the lengths, or depths, to which we've gone). The International Energy Agency now predicts that we won't reach peak petroleum production until at least 2020, and that we may then see a production plateau or slow decline rather than a calamitous plunge *(see Briefing, p. 87)*.

Cook argued that even if we could buy ourselves a few more decades or even a century, a crisis was inevitable—one that would threaten the lives of billions around the world. Although people today tend to think mainly of how a declining oil supply would affect the economy, Cook was more concerned that without abundant fossil fuel or a renewable replacement for it, the global population would be unsustainable.

Population is a function of the rate of useful energy supply, whether or not that energy comes from renewable or nonrenewable resources. If it comes from renewable resources, the rate cannot rise more than briefly above the rate of renewal and therefore populations tend rather quickly to become stabilized in ecological equilibrium with the rate of supply. ...

A population based on nonrenewable resources, on the other hand, faces a much more formidable instability problem. Its rate of usable energy supply depends not on man's efficiency in extracting energy from a dynamic system constantly being renewed but upon the rate he chooses to extract energy from a static system that is not renewable on any time scale meaningful to him. The more he allows his numbers to become dependent on this self-chosen rate, the more he faces ultimate catastrophe. TR

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